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OBSERVATIONS ON GRAVEL TRANSPORT IN FOUR RIVERS IN WESTERN ALBERTA

by

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A THESIS
SUBMITTED TO THE FACULTY OF GRADUATE STUDIES
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE

DEPARTMENT OF CIVIL ENGINEERING

EDMONTON, ALBERTA

MAY 1966

CRITIQUE

The undersigned consider that the Author's terminology for describing methods of gravel sampling (section 4.3 et seq.) is confusing and contrary to established usage. The methods described as "tape samples" and "Wolman samples" might properly be described as "grid samples", because they involve selecting single stones at isolated points established by a real or imaginary grid. In contrast, those described as "grid surface samples" and "samples of grid surface to depth of deepest surface rocks" involve selecting all stones within an isolated square area. The undersigned consider that the term "grid", which implies an open network, should not be used in connection with these last two methods. The terms "square surface samples" and "square samples to depth of deepest exposed stones" are suggested.

ABSTRACT

Colored river-bed stones were used to study initiation of motion and the distance of transport of bed material in two streams of different character and discharges. Concurrently, various modifications of recent methods of estimating the grain size distributions of coarse alluvial sediments were tested. Regime data of the streams and of two others were collected. The results were analysed in terms of tractive force theory and of the regime-slope analysis chart of regime theory; the relevance of the behavior of the colored stones was considered.

The larger colored stones of the channel bed material appear practical as indicators of incipient motion at different stages of flow. Approximate log-normality was found in groups of colored rocks after transport within a limiting distance. The sampling of bed-material by the "stretched-tape" method proved preferable over the other methods tested because of consistency of results and ease and speed of sampling. The choice of sampling method was found to have considerable influence on the estimated median size of the bed-material. However, the use to which the estimated size is put in practice, (ie. roughness calculations in flow formulas), makes the difference in the sizes of secondary importance there. The size of bed-material relative to depth was large, and zero bed-factor was found to vary with relative bed-material size in rather the manner predicted by the experiments of Bhattacharya (1960)

and Qureshi (1962) with 1.7 mm. "gravel" in a laboratory flume; scatter of plotted points prevented a definite conclusion on this matter. The phase of flow-cum-transport was that in which regime equations are stated to be inapplicable without empirical modification. Both tractive force and regime methods were found useful for comparing the results of the surveys with the behavior of rivers in general.

ACKNOWLEDGEMENTS

The author wishes to express his sincere appreciation to all those who have helped in some way to make this thesis possible. Special thanks go to Dr. T. Blench for his guidance and constructive criticism during the analysis of the field data; to Mr. R.K. Deeprose of the Alberta Department of Water Resources for his advice and material help, in the form of equipment and survey party, while carrying out the field work; to members of the field crew; and those others whose advice helped in the task of completing this thesis.

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CHAPTER I

INTRODUCTION

1-1. Reasons for the study: Regime theory presents a method of solving, with fair success, problems of canals built in sandy material. Quantitative problems of sand bed rivers can also be handled when allowances are made for factors such as meandering and natural sequences in discharge (Ref. 1 and Fig. C7-77 in Appendix C). The equations of the theory, however, do not apply generally to small gravel rivers.

The author's interest in small rivers was stimulated by the previous work of Qureshi (Ref. 2), Kellerhals (Ref. 3) and the U.S.G.S. (Ref. 4). Qureshi's work included the application of regime equations to rapid reaches of a gravel river at low discharges. Under such conditions he assumed that the bed material was at the stage of incipient motion and hence an estimate of zero bed factor could be made. This estimate was then used in the analysis of the river by using the regime slope equation. Kellerhals suggested an interestingly new and different set of regime type equations for gravel rivers which were of regime type but carried negligible bed-load. The U.S.G.S. Professional Papers 282 A-G are a collection of articles dealing with the geomorphic and physiographic aspects of rivers.

Little work has been done on wild and loaded small gravel rivers. Verification of the extent to which formulas are affected by the sizes of stone that go into motion at different stages when the range of available stone size is large has had little attention. Hence, the author became interested in trying to observe the movement of painted stones with a relatively large gradation of size in some of these small gravel rivers. The object was to obtain information about the behaviour of bed material under different hydraulic conditions. With this information, it was hoped that understanding of bed load transport could be improved.

1-2. Nature of the study: The primary aspect of the study consisted of tracing the movement of painted stones from a definite location during the sequence of high flows of Summer 1965. A second aspect of the study consisted of analysing bed-material for verification and extension of previous work by others. A third consisted of attempts to fit certain regime type equations to the collected data and interpret the results in terms of the information obtained from the painted rocks.

The probability of useful results could not be assessed. The analysis of the results required regime dimensions of the streams. Hence, a survey party was essential to the study.

The Government of Alberta, Water Resources Branch, carried out the necessary survey work as part of their own programme of river studies and thereby provided the facilites that made the author's work possible.

1-3. Notation and Definitions: All symbols and abbreviations are listed in Appendix A. Explanations of specialized words and phrases are listed below. Further clarification can be found in the references cited.

(a) Regime: Regime may be defined as "the behaviour of a channel, over a period, based on conditions of water and sediment discharge, breadth, depth, slope, meander form and progress, bar-movements, etc..." (Ref. 1).

(b) In regime: When the average values of channel parameters show no trend over a suitable period of time the channel is said to be in regime.

(c) Sediment: Any material, denser than water, that at any time has been transported by water.

(d) Bed-load: The part of the total sediment flow of a stream that is transported by rolling, sliding or saltation.

(e) Suspended load: The part of the total sediment quantity passing through a channel section without resting on the bed.

(f) Bed-load Charge: The weight (in air) of the portion of the sediment flow, moving as bed load, per

second, divided by the weight of water flow per second (Ref. 5).

(g) Dominant discharge: The steady discharge which will produce the same cross section as the natural sequences of discharges (Ref. 1).

(h) Sediment sizes: Clay, silt, sand, gravel, cobbles and boulders will be defined according to the A.G.U. Subcommittee on Sediment Terminology 1947 (Ref. 6), as in Table I. Page 5.

1-4. Suspended load and Bed-load: Bed-load transport is closely associated with suspended load. The latter may differentiate out of the former in different proportions at various discharges.

In channels with graded beds, that is, ones with a wide range of sediment sizes, the influence of turbulence and uplift forces acting on individual particles becomes important. It is not sufficient to consider only the shear forces acting on the particles when investigating the stability of the channel bed. On the well graded bed, the smaller particles are shielded by the larger ones and are protected to some degree from the shear stress acting along the channel bed. The larger stones produce a curvature of flow over and around themselves. This causes a reduction in pressure over the points under the curved flow. If a small particle lies behind

TABLE I

SEDIMENT GRADE SCALE

(Subcommittee on Sediment Terminology, A.G.U.)

	Metric		English
Class and Subclass	Millimeters	Microns	Inches
Boulders			
Very large boulders	4,096-2,048		160-80
Large boulders	2,048-1,024		80-40
Medium boulders	1,024- 512		40-20
Small boulders	512- 256		20-10
Cobbles			
Large cobbles	256-128		10-5
Small cobbles	128- 64		5-2.5
Gravel			
Very coarse gravel	64- 32		2.5-1.3
Coarse gravel	32- 16		1.3-0.6
Medium gravel	16- 8		0.6-0.3
Fine gravel	8- 4		0.3-0.16
Very fine gravel	4- 2		0.16-0.078
Sand			
Very coarse sand	2.0000-1.000	2,000-1,000	0.078 -0.039
Coarse sand	1.000 -0.500	1,000- 500	0.039 -0.020
Medium sand	0.500 -0.250	500- 250	0.020 -0.0098
Fine sand	0.250 -0.125	250- 125	0.0098 -0.0049
Very fine sand	0.125 -0.062	125- 62	0.0049 -0.0024
Silt			
Coarse silt	0.062 -0.031	62- 31	0.0024 -0.0012
Medium silt	0.031 -0.016	31- 16	0.0012 -0.00061
Fine silt	0.016 -0.008	16- 8	0.00061 -0.00030
Very fine silt	0.008 -0.004	8- 4	0.00030 -0.00015
Clay			
Coarse clay size	0.004 -0.0020	4- 2	0.00015 -0.000076
Medium clay size	0.0020-0.0010	2- 1	0.000076-0.000038
Fine clay size	0.0010-0.0005	1- 0.5	0.000038-0.000019
Very fine clay size	0.0005-0.00024	0.5- 0.24	0.000019-0.000010

such a large stone, it acquires an uplift force in excess of the hydrostatic pressure acting on the bed by the amount of reduction in pressure due to the curvature of flow. Due to turbulence in the flow, the magnitude of the uplift force will fluctuate. The effect of this condition was noticed by the author in a glass walled laboratory flume. The condition is marked by a continuous but not constant jiggling of the affected particle. In the field it was indicated by saltating sand grains behind larger stones. When conditions of uplift and turbulence are right the particle is picked up and swept away. It may continue in motion by saltation or become lodged between some other stones. If the discharge were to increase appreciably, the increase in turbulence might be enough to keep the particle in suspension. The problem is that for different intensities of discharge the same particle can exist in different phases of total sediment load, either as bed-load or suspended-load.

Because of the peculiarities just discussed, it is not known with certainty what specified size from the sieve analysis to use in roughness calculations. D_{90} (ninety percent of the material is finer than the specified diameter) was used by Kellerhals in Ref. 3. D_{50} was used extensively by Qureshi in Ref. 2, while D_{90}, D_{75}, and D_{65} were all used in the analysis of the San Luis Canals in Ref. 7.

1-5. An effort to trace bed material transport: The author has read one account which mentioned that shale flakes had moved about three miles during spring runoff and/or from a May rainstorm (Ref. 8). Bed-load transport equations do not attempt to estimate the distance of transport. They just give estimates of the magnitude of bed-load charge for given water discharges.

A method to trace individual particles was introduced in this study. Rocks were painted with a distinct orange acrylic lacquer and placed in the stream before the spring run-off. The paint served to identify the rocks for recovery later in the summer after the sequence of higher discharges.

CHAPTER II

THE FIELD WORK

The field work can be broken down into three phases. The first was the selection of suitable study reaches. Once that had been done, the second phase, that of painting and placing of the colored rocks, was commenced. The third phase consisted of collecting hydraulic data of the streams, testing various sampling techniques and recovering the colored rocks.

2-1. Selection of suitable study sites: The following conditions were considered desirable in a study of this nature.

(a) Clean, coarse gravel would be required for painting.

(b) The rivers should not have a suspended load that would hide the painted rocks at low flow.

(c) The reaches should be clear of obstructions such as beaver dams, water falls, diversions, etc. that would prevent proper assessment of regime slope.

(d) There should be no inflow or outflow between the remote end of the study reach and the gauging station.

(e) Summer flows should be low enough to allow wading and easy access to all parts of the channel bed.

(f) Continuous discharge records should be available for the duration of the study.

(g) Good access should be available to bring in equipment.

With these requirements in mind, a party visited rivers in the Rocky Mountains and foothills of Central and Southern Alberta.

Of the ten sites visited, four were chosen as meeting most of the desired conditions. They were the Castle River near Beaver Mines, the Sheep River west of Turner Valley at Buck's Ranch, the Elbow River near Bragg Creek and Drywood Creek near Twin Butte. Fig. 2-1 indicates their geographic location. See Page 10.

PLATES D2-1 to D2-3 in Appendix D are airphoto mosaics of the reaches studied. No photos were available for Drywood Creek. Figs. C2-1 and C2-2 in Appendix C are maps compiled from transit traverses of the Elbow River and Drywood Creek, respectively. Figs. C2-3 to C2-6 are geological maps of the study areas based on the maps of Refs. 9, 10, 11, and 12.

The Elbow River and Drywood Creek reaches were considered most favourable for the bed material transport study. The Drywood reach appeared quite stable so that not much material would be buried or lost by spill over the banks at high stage. In direct contrast, the Elbow reach was partially braided and considerable overbank spill could occur during high stages. The braided pattern probably indicated high bed-load

charge at high discharges. The extremes in the nature of the reaches held out the possibility of contrasting results.

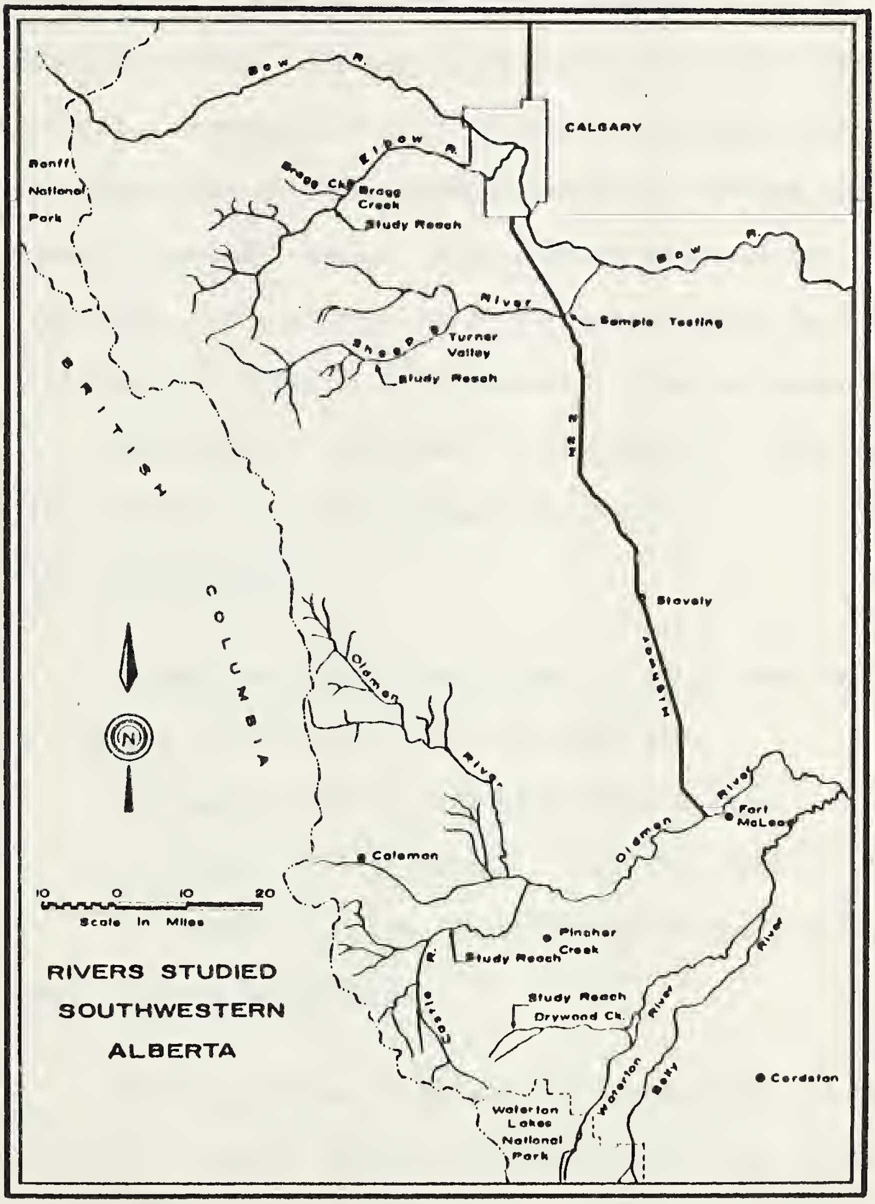


FIGURE 2-1

GEOGRAPHICAL LOCATIONS OF STUDY REACHES

2-2. Bed-material transport: The following sections deal entirely with the field work associated with the painted stones. The rest of the field work is described in Section 2-3.

2-2.1. Painting the stones: During the Winter of 1965, various types of dyes, stains and paints were tested for use in painting the rocks. The use of radio-active tracers was considered. However, the lack of proper equipment, the health hazard and the much greater expense, confined the tests to more conventional means. The material used had to:

(a) have a distinctive color for quick visual detection,
(b) have no effects on the density, size and shape of the material (important in the sand size range),
(c) be easy to apply and hard to rub off,
(d) be economical.

A modified mix of paint used in beach studies (Ref. 13) was chosen. The field mix used was:

1/3 gallon Day Glo 202 Line, Fire Orange
1/3 gallon 10% (by weight) V.M.C.H. (Bakelite Vinyl Resin) - M.E.K. (Methyl Ethyl Ketone) solution,
and, 5/8 gallon Toluene

The Day Glo was thinned with the Toluene and then the V.M.C.H. - M.E.K. solution was added, stirring continuously. The mix was immediately applied with a spray gun after mixing. A gel tended to form if the mix was allowed to stand too long,

plugging the spray gun nozzle.

The painting of the rocks was accomplished in a matter of hours. At the Drywood Creek site, the rocks to be painted were placed on a polythene groundsheet. The stones were then washed using a portable fire-fighting pump and left to dry. After each pass with the spray gun, the rocks were raked over and sprayed with paint again. The process was repeated till sufficient coverage of the stones was attained. PLATES 2-1 and 2-2 show the washing of the stones and a view of the sample when painting was completed respectively.

At the Elbow River site, the same procedure was followed, except the groundsheet was not used as the stones did not require washing. PLATE 2-3 shows the Elbow River sample site with the sample in the windrow where it was painted. See PLATES 2-1, 2-2, and 2-3 on Page 13.

The stones that were painted had a large size range. They were raked into a windrow with the larger stones from the channel bed added to it. No special effort was made to paint the smaller fractions. They became coated while painting the larger stones. The size of stones painted at both sites ranged from about 3/8 to 8 inches in diameter.

Before placing the painted rocks in the water, cross sections were taken at the placement site and U/S and D/S of it. Four X-sections were taken at the Elbow River (see Fig. C2-1).

PLATE 2-1

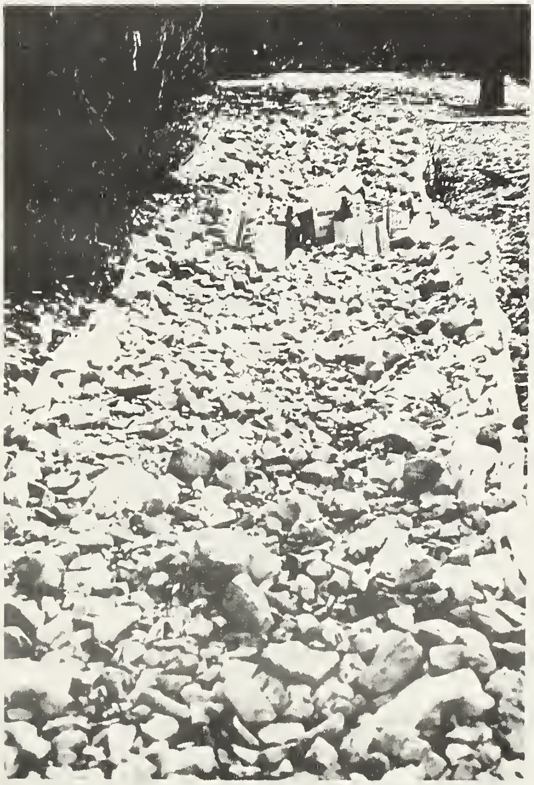


PLATE 2-2

PLATE 2-3

X-section #2, Sta. 32+05, Fig. C2-7 is representative of the initial placement site. This is Sta. 32+05 on the survey baseline. X-section #1, Fig. C2-7 was taken 75 feet D/S of X-section #2. X-sections #3 and #4, Fig. C2-8 were taken 50 feet and 125 feet U/S of #2 respectively. At the Drywood location, 11 X-sections were taken. X-sections H and J, Fig. C2-10 are representative of the initial placement site. The middle of the sample site corresponds to Sta. 12+30 on the survey baseline. X-sections A, C, E, and G are 70, 50, 30 and 10 feet respectively - U/S of section H. X-sections L, N, O, P and Q. Fig. C2-10 are 20, 50, 60 and 70 feet respectively D/S of section J. X-sections H and J are 10 feet apart.

The stones were evenly distributed in a confined area over the stream bed. At the Elbow site, the area of the bed covered by the painted stones was a rectangle of approximately 50 feet by 35 feet and at the Drywood site, the area covered was about 12 feet by 25 feet. At both sites, the larger stones were placed in the deeper part of the channel.

2-2.2. Number of stones painted: An estimate of the number of stones painted was made by using an approximated median diameter (D) of the stones based on sieve analysis and an estimate of the surface area covered per gallon of paint. It was estimated that approximately 2000 and 5000 stones were painted at the Drywood and Elbow sites respectively.

2-2.3. Recovery of the colored stones: Recovery operations were accomplished by wading upstream along the channel, noting the location of any finds and placing identifying marks on the rocks. Walking upstream prevented surface disturbances from obscuring the channel bed. After the information [illegible] the recovery operations was recorded, the stones from the Elbow River were thrown back into the river where they were found with the hope of obtaining more information about their movements from the next recovery operation. The Drywood Creek stones were not replaced. One reason was that they were all brought to one central point for analysis and it would have been difficult to replace them in their proper location. The other reason was that the highest anticipated stage for the summer had passed and no more appreciable movement of the stones was expected.

2-2.3a. Elbow River: The search for the colored rocks was carried out before high flows had occurred. A considerable number of stones was noticed during routine survey work on June 9th, about 1800 feet D/S from their original position. That same afternoon, with a discharge of 472 cfs. flowing, an effort to recover the stones was made. PLATE 2-4 shows the recovery operation.

PLATE 2-4 COLORED ROCK RECOVERY, ELBOW RIVER

A total of 958 painted stones was recovered. On June 10th, the discharge increased to 566 cfs. The increased suspended load prevented further recovery of more stones. The river continued to rise and on June 18th, hit a peak discharge of 4430 cfs. Later, in August, only about one-half a dozen painted rocks were found during two weeks of survey work D/S from the recovery site. The high water of June 18th, had either swept the rocks much farther D/S or, more likely, buried them in some gravel bars. Hence, the recovery of colored rocks on the Elbow River was confined to the one operation before the June flood.

2-2.3b. Drywood Creek: The first attempt to locate colored rocks in Drywood Creek was made on July 7th, during a discharge of 67.3 cfs. - 297 rocks were recovered. Another effort to recover painted stones was made on July 14th. The discharge was 36 cfs. and 59 more rocks were found. The third attempt was made on August 25th, during a discharge of 11.9 cfs. - 208 rocks were recovered. Most of these were found at the initial placement site and from a rapid section about 75 feet D/S from the starting point.

TABLE B-I in Appendix B is a summary of the recovered colored rocks, giving both the size and number of rocks found at specific locations. Fig. C2-11 shows X-sections of the locations of the larger finds on Drywood Creek. PLATE 2-5 (looking D/S from Sta. 43+65) and PLATE 2-6 (looking D/S from Sta. 47+00) show the reach where the colored rocks were found in the Elbow River. PLATE 2-6 shows the deep and shallow channels on the right and left, respectively, of the gravel bar in the background. PLATE 2-7 shows the dry channel (Sta. 27+00 to 28+00) cutting across the point bar where one of the largest recoveries was made along Drywood Creek.

TABLE II summarizes the results of the recovery operations. See Page 18.

TABLE II

SUMMARY OF RECOVERY OPERATIONS

LOCATION	WHEN PAINTED			DURATION OF TEST		WHEN RECOVERED		
	Date	No. of Rocks	Q cfs.	Date	Q_{max} cfs.	Date	No. of Rocks	Q cfs.
Drywood Creek	17/5/65	2000	53.0	18/6/65	446	7/7/65	297	67.3
						14/7/65	59	36.0
						25/8/65	208	11.9
						Total	564	
Elbow River	20/5/65	5000	230	6/6/65	601	10/6/65	958	472
						Total	958	

PLATE 2-5

PLATE 2-6

PLATE 2-7

Only four recovery operations were attempted as shown in TABLE II. Three were along Drywood Creek and one at the Elbow River. Discharge records for Drywood Creek indicated that no further movement of the stones occurred after the first recovery operation. The later operations just produced stones that were passed up during the earlier attempts at recovery.

2-3.1. Hydraulic and physiographic data: The Department of Northern Affairs and National Resources, Water Resources Branch, (D.N.A.N.R.) has continuous stage-discharge recorders near all the reaches studied. Discharge values used in this thesis are based on data from these recording stations. TABLE B-II in Appendix B gives a summary of the annual maximum daily discharges and areas of the drainage basins above the gauge. TABLE B-II is based on the logarithmic normal frequency plots of maximum daily discharges obtained from D.W.R. (Alta.) and given in Figs. C2-12 to C2-15. The hydrographs of the years containing the highest and lowest daily discharges on record are given in Figs. C2-16 and C2-19. The 1965 hydrograph for the duration of the study is superposed on the same figures. Figs. C2-20 to C2-23 show the rating curves and channel X-sections at the gauging sites based on D.N.A.N.R. data.

2-3.2. Longitudinal Profiles: The distances shown on the profiles, Figs. C2-24, were chained along the river banks. The trace of the rivers was followed as closely as possible. The maximum

distance between stations was limited to 200 feet. Due to the tortuosity of Drywood Creek, in some sections, stations at 25 feet intervals were common. Measurements at each station consisted of level shots, where applicable, on water surface, thalweg, high water marks, flood plain and bars. The profiles were detailed and are on record in the Water Resources Office, Department of Agriculture, Edmonton.

2-3.3. Cross-sections: Cross-section sites were chosen for:

(a) being representative of the channel sections,
(b) showing extreme conditions of channel shape, and
(c) being useful in the analysis of the data gathered in the study reach.

In most cases, the X-sections extended up to or beyond the high water marks. However, some were stopped below the high water marks, either because of dense brush or because the river did not affect the flooded area when in high stages as evidenced by the condition of the vegetation and sediment type. Neill, in Ref. 14, suggests that X-sections should include the flood plain. This is important if there is evidence of deposition or erosion occurring on it. With this in mind, X-sections were extended as far as required.

Figs. C2-25 to C2-28 are a few typical X-sections of the Castle, Sheep, Elbow and Drywood reaches respectively. They indicate the nature of the channels encountered in the study. The rest of the X-sections taken are on file in the Water

Resources Office, Department of Agriculture, Edmonton.

2-3.4. Bed and bank sampling: Samples of the material forming the hydraulic boundaries of the channels were taken. TABLE B-III summarises all the samples taken from the four study reaches. The sampling methods that were used are discussed in Chapter IV. PLATE 2-8 shows the scale and calipers used to weigh and measure the stones.

PLATE 2-8

SCALE AND CALIPERS USED IN SAMPLING

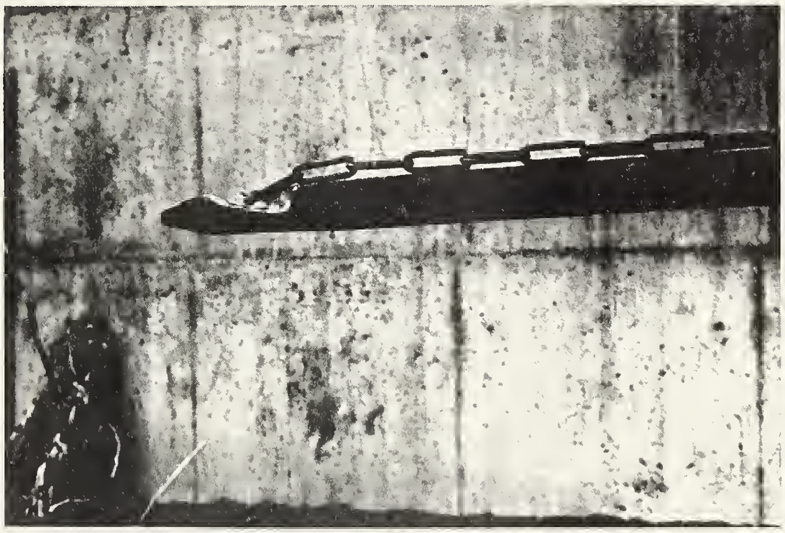
2-3.5. Velocity profiles: A number of velocity profiles were taken using a combined Pitot and static tube. This apparatus is distinguished by its insensitivity to orientation in the flow (Ref.. 15). The sensitivity of the instrument to velocity fluctuations made it very useful in studying turbulence in the flow, but made reading of the manometers difficult. More or less average values of the readings were recorded. Figs. C2-29 to C2-31 show three typical velocity distributions obtained with the tube.

2-3.6. Erosion lines: The rate of erosion on concave banks was measured at two sites on the Elbow River site X (PLATE D2-4 and Fig. C2-32) and site Y (PLATE D2-5 and Fig. C2-33) are shown in the Appendix. Site X was exposed to swift, turbulent impinging curved flow and was just D/S from a rapid section. Site Y was protected by a large gravel bar parallel to the shoreline. A reference line was staked well away from the edge of the bank. The difference in distances to the bank's edge before and after the high stage gave the amount of erosion caused by the high water.

2-3.7. Shifting bed formations: A method of measuring scour and fill in a stream bed has been developed by Emmett and Leopold (Ref. 16). It was tried in the Belly River east of Waterton Park and on the Elbow River. The Belly River site was beside a bridge pier where scour and fill were expected. The Elbow site was on the U/S end of a partially submerged bar near midstream.

The method, discussed in Ref. 16, consists of driving medium weight open link chains into the channel bed. Section 5-4 gives a brief outline of the ideas behind the method. The chains were placed in the channel bed by attaching the bottom link to a steel bar and driving the bar down with a sledge hammer. The bar was extracted when driven deep enough, leaving the chain in a vertical position in the bed. PLATE 2-9 shows the connection of the chain to the bar.

PLATE 2-9 CHAIN-BAR CONNECTION



Difficulty was encountered at times when the bar hit a large boulder preventing further penetration into the bed. When this occurred, the bar was removed and a new location tried. The chains were driven to depths varying from 2¼ to 4 feet. After the chains were in position they were referred in both horizontal and vertical planes to some stable reference point.

Figs. C2-34 to C2-36 show the X-sections at the Belly River site of the chain study area before and after the high summer discharge. The chains at the Elbow River site could not be relocated after the June flood. The area had been covered by about 1½ feet of gravel and cobbles. No evidence of the chains was found when excavation was carried out to their original elevation - leading to the speculation that they may have been washed away before the deposition of the sediment.

CHAPTER III

GENERAL FIELD OBSERVATIONS

3-1. Influence of geological formations: One of the most striking features observed in the field was the influence of geological formations on channel shape and river trace. Reference to the air photos in Appendix D, PLATES D2-1 to D2-3 clearly exemplify this. All the rivers studied had local base levels, determined by rock outcrops. A prime example is shown in PLATE D2-2(a) of the Sheep River. About 300 feet U/S from Station 2+00 is a 3 foot waterfall. Referring to the geological map, Fig. C2-4, the waterfall corresponds to a stratum of the Bighorn (Cardium) formation lying along a fault line. The greater resistance to erosion of this material compared to the surrounding Wapiabi shales adds to the stability of this base level. The Sheep River, through the study reach, appears to be following planes of weakness in the formations of the area. Drywood Creek is also severely influenced by rock outcrops. The Elbow and Castle Rivers are affected to a lesser degree. In nearly all cases where the stream impinged against an outcrop, the depth of flow increased. The outcrop would not erode readily, and thus the increased shear forces acting along the channel beds scoured out the bottom, leaving exposed bedrock or large bed material on the channel bed.

The impinging flow allowed the growth of point bars along the opposite banks in the quieter waters, decreasing the water surface breadth to a limited extent. The limit is fixed by the magnitude of the shear forces acting on the expanding point bars becoming large enough to prevent further deposition there.

Geological formations are a major controlling factor in the pattern and behaviour of rivers flowing through rock outcrop areas. In these situations, regime type analysis must be confined to the short mobile reaches found between outcrops. These analyses must be combined with geologic information in order to obtain practical and realistic results.

3-2. Bed and bank materials: The most striking feature of all the channel beds was the continued presence of fines amongst the coarse material. In reaches with high velocities more of the coarse bed material was exposed than in reaches where the velocities were lower. In the latter case, the fines nearly covered the larger fractions. The continual presence of fines was also noticed by Lane (Ref. 7) in the San Luis Canals of Colorado. However, Figs. C3-37 to C3-39 based on sieve analysis of the Elbow and Drywood reaches, show that running water does have the ability for a limited sorting of bed material. Sieve analysis on the San Luis Canals also showed the sorting action as shown by Figs. C3-40 and C3-41. In all the figures referred to, it is noted that the submerged samples have a larger median size.

Field observations indicated that coarser gravel would move readily over a bed of finer gravel when little or no finer material was in motion. A similar observation was made by Kellerhals in Ref. 3, during flume experiments.

Fig. C3-42 shows the grain size distribution of samples taken at various depths in a hole dug through a small gravel bar. The size distribution of the surface material is from a sample of the larger fraction picked up at random. A more representative grain size curve of the surface material would have a D_{50W} of about 1.5 inches. The strata of sediment at a depth of 4 inches was medium gravel. Below a depth of 4 inches the sediment became coarser. It was impossible to dig further than 20 inches deep and still obtain representative samples, due to the sloughing in of the sides of the hole. The fact that coarse material was found on top of finer sediments confirms the observations of the coarser material being able to move readily over the finer fractions. The observations and data indicate how alternate layers of fine and coarse sediments noticed in many road cuts through alluvial deposits, can be explained in terms of the competence of a stream.

3-3. Channel characteristics: It was observed that in many cases larger boulders along the banks would mark the beginning of a rapid reach. Near the middle of the rapids, the water surface width (W_S) would be a minimum, expanding again below the foot of the rapids. PLATE 3-1 shows this condition.

PLATE 3-1 CONTRACTION OF W_s THROUGH RAPID REACH

A possible explanation of this phenomenon can be explained by noting that the rivers where this condition was noticed had a flashy nature, i.e. flood peaks rise and recede in a matter of a day or two. (See the hydrographs in Figs. C2-16 to C2-19). During these flashy floods, large bed load charges would be picked up from shoals and bars in the channel. Due to the short duration of the flood, the stream does not get the opportunity to sort the bed load charge. As the charge moves along, two or more bars and shoals may be combined into one large mass of bed load charge. As the flood peak recedes rapidly, the charge is deposited in a relatively small area and

[illegible]

[illegible]

forms a type of weir across the channel. During subsequent low stages, the river degrades through the deposit. The channel flows narrower over the deposit for a given discharge because of the steep slope. The reduction in W_s over the steep slope is the noticeable contraction associated with the rapids. Subsequent smaller floods wash away the finer fractions from the deposit leaving the large boulders near the head of the rapids.

CHAPTER IV

TESTS OF SAMPLING TECHNIQUES FOR COARSE SEDIMENTS

4-1. The problem: As yet, there is no generally accepted standard procedure for sampling river gravels. Various methods have been devised. The author tested four variations of an areal type method of sampling using three different size ranges and distributions of sediments. Three conditions governed the selection of the sample sites. First, the site had to be large enough for no overlapping of grids to occur. Second, the various sites had to contain different size gradations to test the suitability of any method for some particular size range. Thirdly, the test areas had to be uniform in composition throughout.

4-2. Review of sampling methods: Wolman (Ref. 17) developed a method of sampling coarse bed material using a surface grid and picking up stones at specific points on this grid. The sieve analysis results were plotted as size of stone vs. percent greater or equal than by number or vs. percent retained by weight. The use of by number implies that, for the area sampled, the number of stones greater than a given size is a specific percentage of the number of stones in the grid. Sieve analysis can also be plotted using the weight of the stones. This method may be used

in conjunction with areal sampling, though the results are greatly influenced by the size range of the stones and the total weight of the sample. For small samples, a few large stones may account for half the total weight, shifting the grain size distribution curve so much that it is no longer representative of the actual surface material sampled. Wolman claimed good reproductivity of the same grain size distribution curve by different operators using his method.

Qureshi (Ref. 2) used Wolman's grid system but plotted the results by weight. His curves did not show too great a deviation from the straight line log. normal plot because in his study reach the size range of the rocks was not extreme. Kellerhals (Ref. 3) used Wolman's method. He used the intermediate axis of the stones instead of sieve size in his plots. The intermediate axis is very closely related to sieve size; the more spherical the stone the closer the agreement. It is important to note that the method of sampling may have a profound effect on the median size and the grain size distribution obtained. It seems that the Wolman method makes the probability of picking a stone larger than a specified size proportional to the surface area covered by such stones and, therefore, not proportional to the number of such stones. The discrepancy between the grid surface sample and the other two methods of Fig. C4-49 may be attributed to this cause.

Kellerhals, (Ref. 18) brings out the same point regarding Wolman type sampling by his carefully worded statement,

"A b_{90} of say 3 inches implies that 90% of the channel bed is covered by stones with an intermediate axis of less than 3 inches".

The advantage of Wolman's method is that it is fast, economical and gives fairly consistent results. Fortunately, the effect of roughness on flow formulas is relatively insensitive to roughness (stone) size.

4-3. Methods tested: All the methods tested are based on Wolman's work in the sense that they are all areal grid surface samples. The difference between tests is in the method of establishing the grid. The four methods tested have been named tape samples, Wolman samples (after the originator), grid surface samples, and samples of grid surface to depth of deepest surface rocks. A grid surface sample is defined as a sample comprised of all the surface stones enclosed in a square of a real or imaginary grid.

4-3.1. Tape samples: A 100 foot survey tape is stretched out over the area to be sampled. The stone falling under each foot mark is picked up. For simplicity in calculations, only 99 stones should be gathered so that the estimated percent retained by number is equal to the number of stones greater than the specified sieve size. PLATE 4-1 shows the tape laid out for a sample. See Page 34.

PLATE 4-1 TAPE SAMPLE

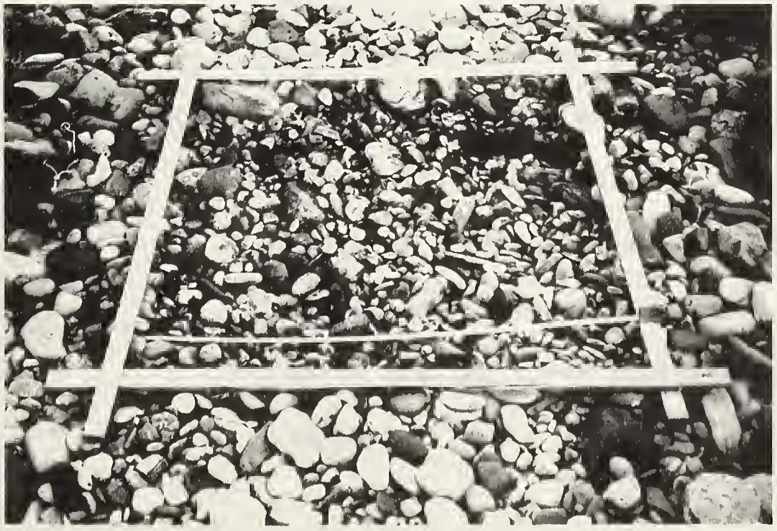
4-3.2. Wolman sample: This sampling method is named after the originator of the method, though all four methods are based on his original work. The grid is established by traversing the area to be sampled and picking up the stones that falls, for example, under the sampler's right big toe. The interval between the stones and the method used to establish the grid, depend upon convenience and size of area to be sampled. The prime consideration is that uniformity in the sampling procedure is maintained. PLATE 4-2 shows an operator demonstrating one of the many methods of establishing a grid and collecting stones for the sample. See Page 35.

PLATE 4-2 WOLMAN METHOD OF SAMPLING

4-3.3. Grid surface sample: A square grid of convenient size is established and all surface material is collected for the sample. The larger the size of the material being sampled, the larger the grid should be in order to obtain a more representative sample. PLATES 4-3 and 4-4 show the before and after pictures when taking a grid surface sample. See Page 36.

PLATE 4-3 GRID SURFACE SAMPLE: BEFORE SAMPLE IS TAKEN

PLATE 4-4 GRID SURFACE SAMPLE: AFTER SAMPLE IS TAKEN



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4-3.4. Grid surface sample to depth of deepest surface rock: This grid is laid out as for the grid surface sample, but the volume of rocks to a depth of the deepest exposed surface rock is considered as the sample. The same considerations as to the size of grid to use are used as in the grid surface sample.

4-4. Conditions at the testing sites: Three different sets of tests were made, two on the Sheep River and one on the Castle River.

Sheep River - Site "A": The material sampled was coarse and had a wide range of sizes. PLATE 4-1 shows the sample site with a tape sample just completed. Fig. C4-43 and C4-44 are the sieve analysis curves of the samples.

Sheep River - Site "B": The gravel sampled was much more uniform and smaller in size. PLATE 4-2 shows the sample site and Figs. C4-45 and C4-46 are the sieve analysis curves of the samples.

Castle River: The sampling site was an extensive point bar, uniform in appearance, containing wide range of sediment sizes. PLATE 4-5 shows the appearance of the site. Figs. C4-47 to C4-50 are the sieve analysis curves of the samples.

PLATE 4-5 CASTLE RIVER SAMPLE TESTING SITE

4-5. Results of the tests: The results of the tests have been presented in the form of frequency analysis curves plotted on log. normal probability paper as sieve size vs. percent retained by number and sieve size vs. percent retained by weight, (Figs. C4-43 to C4-50). The curves indicate that the by number plot gives, in most cases, a closer resemblance to a log. normal size distribution. TABLES B-IV and B-V summarize the results of the frequency curves. TABLE B-V, Site "A", Sheep River, shows only one value for D_{50} and none for D_{84} in four samples. This points out the difficulty in using the

by weight plot for small samples of coarse material. The large material influences the grain size distribution by shifting the sieve curves to the right. This is because the smaller fraction, though numerous, has negligible weight compared to the coarser fractions. TABLE B-IV shows the effect of plotting the same samples by number. It is expected that if large enough samples are taken, the by weight and by number methods of plotting will give equivalent results.

The TABLES (B-IV and B-V) indicate that for material of gravel sizes and smaller, the by weight and by number methods of plotting both give satisfactory results. For material finer than coarse gravel, the author recommends the by weight method from the point of view of convenience and speed of sampling. For this type of material, 75 pound samples should produce a fairly representative grain size distribution curve. The larger the sample the more representative the curve will be.

The grid surface samples resulted, by both methods of plotting, in a shifting of the grain size curve to the left, indicating a relatively larger proportion of fines. The grid surface to depth of deepest surface rock caused even a greater shift to the left.

The logarithmic standard deviations of the cobble material indicate that the Wolman method gives a smaller range of sizes between D_{84} and D_{16} than the tape sample method does. The reason lies in the manner of establishing the grid. In the

coarse material the operators foot does not enter into the small gaps between the larger stones, resulting in a grain size curve weighted towards the larger fraction of the sample. In the gravel sizes the foot can envelop a larger size stone resulting in the collection of an excess number of finer fractions. The tape grid overcomes the difficulties.

4-6. General considerations: Human judgement is involved in the Wolman sampling method. This will tend to produce variations in the grain size curves obtained by different samplers. The tape method reduces this factor, in that the rock to be picked up is fixed by the tape grid.

The tape sample is impractical for underwater sampling. The Wolman method can be carried out to depths of about 3 feet, depending upon the velocity of the flow and the footing on the bed. In swift water the sampling becomes extremely "random" as the operator is swept downstream. PLATE 4-6 shows a Wolman sample being collected from the river bed.

PLATE 4-6 WOLMAN'S SAMPLING OF BED MATERIAL

[illegible]

[illegible]

4-7. Conclusions and recommendations: A sample should represent the grain size distribution of the natural deposit as closely as possible. The larger the sample is, the more likely it is to represent the distribution. Time and economics limit the size of the samples. With these considerations, the author recommends a minimum of 99 stones per sample for cobbles and very coarse gravel when analysed with the by number method. Analysing material finer than very coarse gravel by weight would require a minimum sample of 75 to 100 pounds.

Samples should be taken where the distribution of shape and sizes of the stones appear uniform. Samples of different sortings should be taken individually as different distributions of rock sizes are the result of different hydraulic conditions.

For sizes ranging from very coarse gravel up to the boulder class, the tape samples and the Wolman samples give, for most practical applications, the same grain size distribution curves.

Based on the field work and analysis of the data, the tape sample, plotted by number, is the best of the four methods tested. It is preferred because it has the three qualities of:

(a) close representation of grain size distribution,

(b) good reproducibility of distribution curves amongst different operators, and

(c) ease and speed of sampling.

CHAPTER V

ANALYSIS OF FIELD DATA

5-1. Sieve analysis: The regime slope analysis and the tractive force analysis by Lane in Ref. 16 both use sieve size by weight. Kellerhals followed Wolman's suggestion and used intermediate diameter by number in his analysis of the San Luis Canal in Ref. 3. The relation of D by number and D by weight depends upon the size, shape and the density of the various types of rock. In Ref. 2 a relation of $D_{50W} = 1.8\ D_{50N}$ was obtained. Figs. C5-51 to C5-54 show the relationships between D_{50W} and D_{50N} based on sieve analyses on the rivers studied. The results of this study gives three values larger and one about the same as in Ref. 2. TABLE III lists the arithmetic average of the ratio D_{50W}/D_{50N} and the equations of the best fit lines of Figs. C5-51 to C5-54 for the rivers studied.

TABLE III

RELATIONSHIP BETWEEN D_{50W} AND D_{50N}

RIVER	D_{50W}/D_{50N}	BEST FIT LINE
Castle	2.123	$D_{50W} = 2.15\ (D_{50N})^{.983}$
Sheep	2.465	$D_{50W} = 1.87\ (D_{50N})^{1.46}$
Elbow	2.424	$D_{50W} = 22.8\ (D_{50N})^{.183}-10$
Drywood Creek	1.847	$D_{50W} = 1.8\ \ D_{50N}$

The results of sieve analyses shown in TABLE B-III were averaged for each river studied. The averaged sieve analyses were used in the analysis of Chapter VII. TABLE B-VII shows the values used.

5-2. Velocity profiles: The velocity distributions observed are unlike those given in standard text books for ordinary open channel flow. Instead, they show centers of high velocities in low velocity areas and conversely (Figs. C2-29 to C2-31). These high velocity areas are believed to be due to high speed vortexes projected through the fluid much like smoke rings through air. The vortices might be formed by water flowing over some projection in the channel bed or sides and literally peeling itself off the object at the surface of discontinuity. These centers of high velocity may be of considerable importance in determining the initiation of movement of particles on the channel bed and sides as discussed in Section 1-4. Their effect will undoubtedly be difficult to evaluate as their occurrence appears to be at random. The figures show that the channel bed is shaped in accordance with the location of these high velocity concentrations.

5-3. Erosion lines: Figs. C2-32 and C2-33 indicate the erosion that occurred during the summer of 1965 along the Elbow River bank erosion sites. Site X had a maximum of 6.5 feet eroded away from the bank. This occurred just D/S of a very large boulder whose wake can be seen in PLATE D2-4. This would indicate the significance of the combined effect of turbulence and jetting

action, caused by the constricted flow, on the erosive power of the water. The rock might also produce the high speed vortexes discussed in Section 5-2 which would help to erode the bank further D/S. Site Y had a maximum of 1.8 feet of erosion. The smaller figure can be attributed to the protection from the off-shore bar. It is estimated that site X lost about 125 cubic yards and site Y - 21 cubic yards to the erosive action of the river.

5-4. Shifting bed formations: The idea of estimating bed elevation changes by the use of chains is relatively new (Ref. 16). Chains are driven into the channel bed below the anticipated scour depth. The tops of the chains are located both vertically and horizontally relative to a fixed reference point. By relocating the chains after the passage of a flood, the scour and/or fill at the point can be determined. Thus, if scour has occurred, the exposed links will lie flat, pointing D/S; the number of links exposed is a measure of the degree of scour. If scour is followed by fill, the horizontal links will be covered by the depth of the fill; the number of horizontal links indicates the degree of scour previous to the aggradation. By noting the orientation and number of links exposed before and after a flood, an indication of the processes occurring during the period can be obtained. The method does not indicate when erosion or deposition occurred; it may give the impression that only one cycle of deposition and/or scour occurred, whereas, there may have been many - as in the passage

of dunes on sand beds. The chains can give a true estimate of the maximum scour that occurred. The final deposition recorded after the flood may not be the maximum value that had occurred during the flood. The method gives more useful results when a large number of such chains is used over a fairly extensive reach.

Referring to Figs. C2-34 to C2-36, showing X-sections C-1 to C-3, it is noted that degradation occurred at all three chain sites. At X-section C-1 and C-3 deposition had followed the initial scour.

At X-section C-1, the river had eroded 0.58 feet and then aggraded 0.08 feet (D/S end of bridge pier).

At X-section C-2, the river had degraded 0.54 feet with negligible aggradation following. (middle of bridge pier).

At X-section C-3 the river had degraded 0.65 feet and aggraded 0.35 feet (U/S end of bridge pier).

In each case, the chain was found with the top exposed links lying horizontally in a D/S direction.

The results indicate that most of the bed activity was located near the U/S end of the pier. However, the final result was that the scour hole around the D/S end of the pier had increased in size. The greater amount of aggradation on the U/S end of the pier can be partially attributed to the small amount of driftwood that had lodged on the gravel shoal a few feet U/S of X-section C-3.

CHAPTER VI

ANALYSIS OF RECOVERED COLORED ROCKS

6-1. Manipulations of the data: Sieve analyses of all the recovered colored rocks were made. The results were plotted on log probability paper as sieve size vs. percent retained by weight and by number. Figs. C6-55 and C6-56 show the grain size distribution curves of all the recovered rocks for the Elbow River and Drywood Creek respectively. The Drywood Creek recovery had sizes ranging from 6 to 3/8 inches, while the Elbow River study had sizes from 3 to 3/8 inches in diameter.

A comparison of rocks colored and rocks recovered for the Elbow River is given by Fig. C6-57. It is noted that the larger fractions of the sample were not recovered. A large number of these larger rocks had been noticed in a rapid section about 900 feet below their initial point of placement. Recovery of these stones was not made as explained in Section 2-2.3(a). The largest fraction of the painted stones had not moved any significant distance away from the initial placement site. One stone, estimated as about 25 pounds had moved about 15 feet when last observed. A plot similar to C6-57 could not be made for the Drywood site. No samples of the material painted were made before painting the rocks. When the site

was revisited the bar where the rocks were taken from had become covered with sand and gravel. PLATES 2-1 and 2-2 give an indication to the size of material painted at the Drywood site.

Figs. C6-58 to C6-61 show the sieve analyses from the four major divisions of rock recovery on the Elbow River. The figures show a slight decrease in size with distance downstream. Figs. C6-62 to C6-64 show the sieve analysis curves for some major recoveries along the Drywood reach. The plot of weight of stones vs. percent exceeded or equal to is also shown on these plots. This type of plot was not possible for the Elbow River rocks, as the weight of individual stones was not taken for stones smaller than 1½ inches in diameter. The plots indicate that the size distribution is more nearly log - normal for the shorter distance of movement D/S. This would imply that flowing water requires a minimum distance and period of time before sorting of the stone sizes becomes noticeable. This is shown by plots C6-62 to C6-64 where stones weighing more than 10 pounds are found in the same area as 0.01 pound stones. No stones larger than 5 inches in diameter were found past Station 28+00, or 1570 feet D/S from the starting point, along the Drywood reach. This distance may be some indication of the minimum distance required before the sorting action of the water becomes noticeable. Another factor that may help to account for the large range in sizes at the three locations, is the observation that large stones seem to move over beds of

fine material more readily than the fine material as mentioned in Section 3-2. This phenomenon would allow the larger stones to move D/S at lower discharges while the finer fractions are nearly stationary. With higher discharges, the finer fraction would attain a higher transport velocity than the coarse fraction and overtake it. As the discharge dropped, below the initial value, the movement of most of the particles would cease, resulting in the situation shown by Figs. C6-62 to C6-64.

The recovered painted rocks were analysed for variation of size with the distance of transport. The distance used was measured from the initial placement site through to half the length of the short segments of the study reach in which enough rocks were found to make a sample large enough for frequency analysis. The number of rocks per sample ranged from 279 to 15 at Drywood Creek reach and from 367 to 167 at the Elbow River site. Plots of variation of particle size with distance travelled, plotted by weight and by number, are given in Figs. C6-65, C6-66 and C6-67, C6-68 for the Elbow River and Drywood Creek reaches respectively. All the plots show a decrease in size with increasing distance.

A summary of the plots above is given in TABLE IV. See Page 49.

TABLE IV

SIZE AND LOCATION OF RECOVERED COLORED ROCKS

River	Composite Sample				Average Distance of Transport in Feet[a]									
	D_{50W}	D_{90W}	D_{50N}	D_{90N}	0	75	495	1250	1450	1700	2150	3950	5200	7500
Elbow River	1.55	2.65	1.07	1.65				1.6 1.2	1.5 1.15	1.38 1.00				
Drywood Creek	4.0	6.5	1.6	3.5	5.4 3.4	3.7 1.6	3.5 1.48				2.7 1.5	1.65 1.35	1.6 1.45	1.5 1.42

[a] MEDIAN SIZES BY WEIGHT AND BY NUMBER IN INCHES RESPECTIVELY

A plot of median size of stone by weight and by number vs. the distance travelled based on TABLE IV is given in Fig. C6-69. The scatter in the by weight plot is quite large. The by number plot of the Drywood Creek data gives a reasonable fit to the line $D_{50N} = 1.9\ (\text{Distance})^{-.0445}$ where D_{50N} is in inches and distance in feet. However, when the Elbow data are added the scatter is large. This indicates that the relationship holds only for the one stream and is therefore of no practical value outside the reach studied on Drywood Creek. It is clearly dependent upon the geometry of the channel, shape, size and density of moving stones, the sizes and distribution of the bed material and both the sediment and water discharges.

The maximum distance travelled was 9170 feet by a 1.5 inch diameter stone down Drywood Creek. It was found July 7th about 4 inches above water level in a backwater area, 51 days after it had been put in the water. The discharge records indicate that this movement might have occurred in approximately 23 days out of the 51 - while the discharge was greater than 100 cfs.

6-2. Dimensional considerations: Besides obtaining some indication as to the distance a river sediment can travel, the colored rocks helped in supplying data on incipient motion of bed materials. Consider the question, "For a given discharge, what maximum size of stone will just move under the imposed

hydraulic conditions when there is no suspended load and negligible bed load charge?"

The variables to consider are:

V	velocity	LT^{-1}
d	depth of flow	L
D	some measure of stone size	L
ρ_s, ρ	mass density of stone and water respectively	$FL^{-4}T^{2}$
g	acceleration due to gravity	LT^{-2}
ν	kinematic viscosity of water	$L^{2}T^{-1}$
X, Y	parameters describing shape and distribution of stones on bed	dimensionless

Using Buckingham's Phi Theorem and dimensional analysis will give the non-dimensional groups affecting the problem previously stated.

The variables can be written in the form :-

$$\text{fn.}(V, d, D, \rho_s, \rho, \nu, X, Y) = 0 \qquad 6\ (a)$$

Applying a dimensional analysis the following non-dimensional relations are obtained :-

$$D/d = \text{fn.}(gd/V^2, \nu/Vd, \rho_s/\rho, X, Y) \qquad 6\ (b)$$

X and Y are dimensionless and ρ_s/ρ is constant.

6-2(a). Plot of V^2/gd vs. D/d: A non-dimensional plot of V^2/gd vs. D/d where V is the mean velocity is shown in Fig. C6-70. Referring back to the relationship of 6-2(b), it is noted that incipient

motion is also a function of the Reynolds Number, Re. Hence, the non-dimensional plot should have curves of equal values of the Re drawn on it. A Re in terms of the particle size D was calculated for each point. The scatter was very large and no trend was distinguishable. However, if the laboratory data were considered separately, it was noted that a line of Re of about 750 could be drawn through the points. The field data indicated a family of Re curves through the points with the Re number decreasing for decreasing values of V^2/gd for a given relative roughness. Re values ranged from 659,000 down to 32,000 for the field data. The wide scatter in values of VD/ν, that made contouring difficult, can be attributed to two reasons. First, the data came from various sources, each with different degrees of accuracy in recorded observations. Appendix E gives a description of each source of data. Second, there are three different conditions plotted on the same graph under which the supposedly incipient motion occurred. The Elbow data involve small sizes moving over larger sizes; the laboratory data (Refs. 2, 19, 20) involve material differentiated from the bed material; the field data of Ref. 21 involve coarse materials moving over a pavement of fines. $(\nu g)^{1/3}D/\nu$ could also be used instead of VD/ν as in (Ref. 1, Fig. 10-4). However, considerable scatter would still be expected due to the reasons mentioned above.

V^2/gd can be considered as a Froude Number, Fr, squared, in terms of the depth of flow. Fr is a measure of the

ratio of the inertial forces over the gravitational forces. V^2/gd can also be though of as the regime equation bed factor. F_b or F_{bo} (depending on charge), made non-dimensional by dividing through by g.

The greater scatter of points on the V^2/gd vs. D/d plot (caused to a degree by crude data) indicates the need for great care when obtaining data. The data from Ref. 21 should probably plot lower than they do because the stones were in motion when collected, whereas the stones in other data were in a state of incipient motion. However, the plot does indicate the importance of Re. In low velocity flows where the viscosity of the fluid affects the flow and in supercritical flows where turbulence effects are small compared to the mean velocity, the values of Re may be of considerable importance in the problem of incipient motion.

6-2(b) Plot of $\rho V_{mc}{}^2/(\gamma_s-\gamma)D$ vs. D/d : By manipulating the variables of 6 (a) in a slightly different manner and using the idea of a competent mean velocity V_{mc}, the following relationship results:-

$$V_{mc} = \text{fn.}\ (\ \rho,\ \nu,\ g,\ D,\ d,\ \rho_s,\ X,\ Y\ )$$

and reduces to

$$\rho V_{mc}{}^2/(\gamma_s-\gamma)D = \text{fn.}(\ Vd/\nu,\ D/d,\ \rho_s/\rho\ ,\ X,\ Y\ ) \qquad 6\ (c)$$

Fig. C6-71 is a plot of $\rho V_{mc}{}^2/(\gamma_s-\gamma\ )D$ vs. D/d. The same arguments concerning the Re apply to this figure as were discussed for Fig. C6-70. $\rho V_{mc}{}^2/(\gamma_s-\gamma\ )D$ can be considered as

a measure of the ratio of the drag and lift forces acting on the particle of diameter D over the submerged weight of the particle. By dividing the top and bottom of the ratio by ρ , a Froude Number squared, in terms of the particle size, is obtained. Fig. C6-71 implied that for a given depth of flow, the larger the material the larger the mean velocity required to move the stone. This is because when the depth is large compared to the size of the particles, the velocity in the region of the particles is smaller due to the bed friction so that the mean velocity must be greater for greater depths of flow in order to produce the same shear or tractive force on the stream bed.

In actuality, Figs. C6-70 and C6-71 are different plots of the same physical relation.

It is of interest to note that the V^2/gd vs. D/d plot would be the type of plot used in the regime theory approach to incipient bed material motion (Ref. 1, Fig. 10-4). Plot C6-71 uses the parameters that would be the result of a tractive force or shear stress approach to the same problem.

The functional form of 6 (c) can be written in terms of shear stress τ acting on the bed of the channel such that:-

$$\tau/(\gamma_s-\gamma)D = \text{fn.}(\ V_*D/\nu,\ D/d,\ \rho_{s/\rho},\ X,Y\ ) \qquad 6\ (d)$$

where τ is defined as $\tau = \gamma R S$ or $\gamma d_x S$ for

wide shallow channels. V_* is the shear velocity and is defined as $V_* = (gd_x s)^{\frac{1}{2}}$.

In Ref. 1, p. 142, Blench does a dimensional analysis in terms of the regime theory parameters. Neglecting suspended load his results are:-

$$V^2/gd = \text{fn.}(\ C,\ (g\nu)^{1/3}D/\nu,\ D/d,\ b/d,\ \rho_{s/\rho},\ X,\ Y\ ),\ \text{and} \qquad 6\ (e)$$

$$V^2/gdS = \text{fn.}(Vb/\nu,\ (g\nu)^{1/3}D/\nu,\ C,\ D/d,\ b/d,\ \rho_{s/\rho},\ X,\ Y\ ) \qquad 6\ (f)$$

where C is the charge. He then shows how to manipulate these equations to obtain the Einstein bed-load function parameters. The result is:-

$$\phi = \text{fn.}(\ \rho V_s^2/\gamma D,\ \psi,\ b/d,\ D/d,\ \rho_{s/\rho}\ )$$

It becomes apparent that the above mentioned methods result in "equivalent" parameters. The problem is to acquire enough reliable data which contains all the pertinent information required for a satisfactory analysis. When these data become available, bed load transport problems will be handled with more assurance than at the present.

6-3. Limitations of the Colored Rock Data: The data obtained in the colored rock study do not give the necessary information to describe completely the movement of the stones along the channel bed. Section 6-1 points out the crude assumption underlying the estimation of the ratio of travel of the stones. Future investigations with laboratory flumes, where conditions can be controlled, should include the correlation of the rate

of transport of differently sized particles to the mean velocity of flow in the channel. Attention should also be given to the types of movement that can occur, namely, rolling along the bed, saltation, and suspension.

6-4. Recommendations: The results of the colored rock tests indicate that the method holds promise as a practical method of estimating sizes of material moving as bed-load in small gravel streams with negligible suspended-load. More research could be done to find possible new dyes and paints for marking. Radioactive tracers and polythene coatings that can be shrunk on to the stones should also be given more consideration. The paint solution used in this study stood up quite well to the abrasion and impacts to which it was exposed. Longer life of the paint is anticipated if more V.M.C.H. (bakelite vinyl resin) could be dissolved in the M.E.K. (methyl ethyl ketone) solution before mixing with the paint. A very high speed, enclosed mixer would be required to achieve the desired solution of the bakelite in the M.E.K. and the mixing of the paint-toluene-V.M.C.H.-M.E.K. solution.

Future studies should concentrate on painting the largest bed material available at the site. For the Elbow River this would be 10" to 14" material. Smaller material must also be painted in case the anticipated high stage is below the average annual flood. Based on field experience a minimum of 3000 stones should be painted. A bright yellow color may be better than the orange used as more people are color blind to reds and greens than to yellow.

CHAPTER VII

REGIME ANALYSIS OF GRAVEL BED RIVERS WITH BEDLOAD CHARGE

The analysis is done in two parts. The first is based on that of Kellerhals (Ref. 3), the second, on the slope analysis method of Blench and Qureshi (Ref. 22).

7-1. Channel properties at representative discharge: Both methods of analysis mentioned above require estimates of "dominant discharges" or "representative discharges". The representative discharges of the rivers studied have been chosen with return periods of 5 to 10 years. (See Appendix C, Figs. C2-12 to C2-15). A summary of dimensions of channel X-sections at representative discharge is given in TABLE B-VI. TABLE B-VII is a summary of the average values of the different variables used in the analysis that follows in the next two sections. TABLE B-VIII gives the same data from Ref. 7 (San Luis Canals) and the gravel rivers of Central British Columbia from Ref. 3. The San Luis sieve diameters, given as by weight in Ref. 7, were divided by two to convert to "by number" sizes. The factor two is based on the results of this year's field work.

7-2. Combined Tractive Force - Regime analysis: Kellerhals' method of analysis (Ref. 3) of rivers with negligible bed-load charge

is based on a logarithmic velocity distribution, a power law for velocity and regime type equations for water surface width. In his analysis of the San Luis Canals, Kellerhals used the sieve analysis data of the natural bank material (Fig. C3-41), to obtain his values of D_{90}. The values of D_{90} in this study are based on the sieve analysis of the bed material; selected samples are shown in Fig. C3-40. Kellerhals converted the by weight San Luis Canal samples to by number samples on the basis of his areal surface samples from the Chilko River. These samples were taken by picking all the stones with b greater than 0.2 feet exposed within a certain area.

The rivers of Ref. 3 had a negligible bed-load so the regime relations can be written of the type:-

$$W_s,\ d_x,\ V,\ S \ = \ \text{fns.}(\ Q,\ \text{bed material}\ ) \qquad 7\ (a)$$

The four equations developed in Ref. 3 satisfy the above relationship. The following analysis is for the purpose of finding 4 equations, one for each of the dependent variables on the left side of equation 7 (a), using the data from Ref. 3 and the field data of this study.

A plot of water surface width, W_s at representative or dominant discharge gives the relation (Fig. C7-72).

$$W_s = 1.95\ Q^{1/2} \qquad 7\ (b)$$

which agrees with that found in Ref. 3. The Castle and Elbow Rivers plot above the best fit line. This might indicate that at the representative discharge, these rivers carry a substantial

bed-load charge. It is noted in the literature that large bed-load charge is associated with broad shallow rivers. (Ref. 23, 24). The Sheep River is suspected of carrying a large charge at high floods. However, through the study reach it is an incised river flowing between shale cliffs up to 250 feet high. Hence, the sides are relatively inerodible and prevent the river from attaining its desired wide, shallow regime X-sectional shape. Use of $b = \sqrt{\frac{F_b Q}{F_s}}$ as in Ref. 1, Para. 11.12 allows for this through F_s.

Tractive force was used in Ref. 7 in analysing the San Luis Canals. Assumptions used were that there was negligible bed-load charge and that a limiting shear value existed for which no bed material would be in motion. The limiting shear force is considered to depend upon the diameter of the sediment and on the angle at which the material is lying. Fig. C7-73 to C7-74 are plots of tractive force,

and the specified bed material sizes D65 and D_{90} respectively. The best fit lines are:-

$$D_{65} = .47 \; (\gamma d_x \; S)^{1.34} \qquad 7\ (c)$$

and

$$D_{90} = .75 \; (\gamma d_x \; S)^{1.47} \qquad 7\ (d)$$

In both plots the D_{65} and D_{90} of the rivers studied plotted below the best fit line. In the rest of this analysis equation 7 (d) will be used as it seems to fit the data best. The Sheep River point should be plotted a bit higher as an unfair number of samples of fine material was included in calculating D_{90}. The fact that the rivers studied plot below

the fitting line may be an indication of bed load-charge. An analogy to friction coefficients can be used to explain this. Elementary physics tells us that the static coefficient of friction is greater than the kinetic one. Hence, as movement is initiated along the bed, the tractive force required to keep the particle in motion is less than the critical or limiting tractive force.

The rivers studied plot remarkedly close to the fitting line when b_{90} is used instead of D_{90}. The b_{90} as used in Figs. C7-73 and C7-74 is the intermediate axis of stones assumed to be active bed material at high discharges. From their position on the plot, the b_{90} values could be an indication of the size of material that would form a bed pavement at the dominant discharges.

From equation 7 (a) the next variable for which an equation is required is the mean velocity, V. Energy losses in rivers can be given by the equation (Ref. 3).

$$V / V_* = 5.66 \log 11.2 R / k_s \qquad 7\ (e)$$

which is based on the work of Keulegan, where k_s is the Nikuradses equivalent sand grain roughness and V_* is the shear velocity, $(gd_xS)^{\frac{1}{2}}$. k_s will be estimated by using D90 and b_{90} from sieve analyses. The difficulty lies in the fact that energy losses in rivers are the combined result of grain roughness and flow around bars, meandering and bed roughness. No estimate of the proportion of the losses resulting from each

factor was made in this study. Hence, the anticipated scatter of calculated values should be quite large.

Fig. C7-75 shows the plot of V/V_* vs. d_x/D_{90}. A fourth root, a sixth root as well as the logarithmic velocity equations are shown. The author prefers the sixth root one:

$$V / V_* = 7.7 \left(d_x / D_{90} \right)^{1/6} \qquad 7\ (f)$$

The form of the sixth root equation is that of the rigid boundary Manning equation when $R \approx d$ resulting in:-

$$V / V_* = 1.49 \left(d / g^3 n^6 \right)^{1/6} \qquad 7\ (g)$$

The result is reassuring because the idea of a tractive force design implies that the boundaries of the channel are stable and there is a negligible bed-load charge.

The scatter of the points is probably due to the fact that in the rivers studied, except the Castle, there is more energy loss due to channel roughness, meandering and flow around bars than there is to grain size roughness. The observation that Mannings n may decrease with stage is explained by the use of regime equations in terms of C, W_s, R and d in Refs. 1, 23. This fact will also help to explain the plotting below the fitting of the rivers studied.

A test of equation 7 (f) can be made by substituting equation 7 (d) into 7 (f) thus obtaining a relationship between the sediment size and the channel slope.

The substitution gives the relation:-

$$V \propto (d_x^{1.65} S)^{.255} \qquad 7\ (h)$$

The proportionality is tested in Fig. C7-76. The fitting line is:-

$$V = 18 (d_x^{1.65} S)^{.27} \qquad 7\ (i)$$

The fourth equation can be obtained from the equation of continuity and is:-

$$Q = V d_x W_s \qquad 7\ (j)$$

The four equations derived are reviewed:-

$$W_s = 1.95\ Q^{1/5} \qquad 7\ (b)$$

$$V = 7.7 ({}^{d}x / D_{90})^{1/6} (g d_x S)^{1/2} \qquad 7\ (f)$$

$$V = 18 (d_x^{1.65} S)^{.27} \qquad 7\ (i)$$

$$Q = V d_x W_s \qquad 7\ (j)$$

Comparison of the above equations with those in Ref. 3 indicates a slight difference in the constants and indices. The difference is caused by the conversion of the San Luis Canal data as discussed in Section 7-2.

7-3. Comments on the use of Tractive Force Theory: The relatively poor fit of the rivers studied this summer to an analysis based on tractive force makes its application to rivers, in general, doubtful. The method appears to work quite well when there is no bed-load charge.

The scattering of points in Figs. C7-73 and C7-74 is probably due to the neglect of shape factors, size and

distribution of bed material on tractive force intensity. Another cause is that in a few of the San Luis canals some bed-load charge was present. The effect of bed-load is seen from the rivers studied this summer.

By considering the best fit line of Figs. C7-73 and C7-74 as a basic relationship, the plots can be considered as a type of classification chart. Points not falling near the line then draw attention to the possibility that there may be errors in the raw data or that the stream has a high bed-load charge and/or the D/d ratio is large enough for the phase of flow to be such for which regime theory equations are stated not to apply. A better fit is obtained by using b_{90} (the intermediate diameter of assumed active bed material at high discharges) instead of D_{90} (the sieve size from river bed samples). Hence, b_{90} in Fig. C7-74 probably gives a better estimate of the size of material that constitutes bed-load charge at some high flood.

7-4. Regime Slope Analysis: This analysis is based on the regime slope equation

$$S = \frac{F_{bo}^{11/12}}{K b^{1/6} Q^{1/12}} f'''(C) \qquad 7\ (k)$$

By plotting $Z = Sb^{1/6}/F_{bo}^{11/12}$ at dominant discharge, Q, the plot of Fig. C7-77 resulted.

The slope equation 7 (k) applies to straight regime canals flowing at dominant discharge with bed-load moving in dune formation. To apply it to rivers would require correction factors k for meandering,] for dominant discharge estimates

and m for other factors such as suspended load, bank roughness, etc. The plot of Fig. C7-77 uses k=2 from field experience and assumes l and m are unity. Two lines are drawn parallel to the bottom line which represents the ideal sand-bed canal with vanishing charge. The middle line represents a meandering regime canal with negligible bed-load charge. The top line represents a meandering stream with a bed load charge of about 10 ($f'''(C) = 2$). Few rivers have charges greater than this under dominant discharge conditions. Ref. 1 emphasises, repeatedly, that the regime equations do not apply for small gravel rivers in which d/D is less than about 50.

The four rivers of the study were analysed at dominant discharge conditions using D_{90} from bed material sieve analysis and the b_{90} of what was assumed to be active bed material at higher discharges. Both by weight and by number analyses were used in estimates of F_{bo}. The points are plotted on Figs. C7-78 and C7-79 respectively. All the points plot above the upper line indicating that the rivers have a high bed-load charge, or that d/D is less than about 50.

7-5. Applicability of Regime-Slope Analysis: Warnings as to the applicability of the regime analysis to small gravel rivers are given in Ref. 1. A plot of the d/D ratios at each sample site from the Sheep and Castle rivers did not show any pattern or trend when plotted on the Z - plot as shown in Fig. C7-80. Reference to Figs. C6-70 and C7-80 indicates that none of the

data fall even close to a top limit of $d/D = 50$ for the river gravels. For the 1.7 mm. "gravel" size, Ref. 1 gives the d/D limit as about 250. So, Fig. C7-80 serves the purpose (Ref. 1, paras. 11.6, 11.7) of drawing attention to the phase of flow. The erratic scatter of Fig. C6-70 can be attributed to the causes discussed in Section 6-2(a). With the data available it is not possible to test for the influence of all the parameters that influence the flow. The results indicate, however, that the d/D ratio is not the only important one affecting the phase of flow.

Ref. 1 states that it has become apparent that F_{bo} found from the standard regime formula or Fig. C7-81 (Ref. 5) may have to be multiplied by a factor ranging up to about 3 to bring the points into the double band of Fig. C7-77. The order of the correction is verified by the points for coarse material plotted in Fig. C7-80.

7-6. The Problem of Small Loaded Gravel Rivers: The analyses carried out in this thesis show no sound method of analysing small loaded gravel rivers. It appears, consistent with statements on phase in Ref. 1, that they fall in a phase between the ranges of applicability of the regime equations and tractive force methods of analysis. This condition is analogous to pipe friction problems. One phase of flow is laminar the other extreme is turbulent; in between is the transition stage where both phases of flow have varying degrees of influence.

Dimensional considerations point out the parameters affecting flow in these rivers. To study these and learn their effects on the phase of flow in these types of streams would require very large laboratory flumes through which alluvial channels could be maintained. The size of the flumes must be large enough to reduce the effects of model scaling and surface tension effects.

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APPENDIX A

SYMBOLS AND ABBREVIATIONS

SYMBOLS

b	intermediate axis of stone
C	bed-load charge in parts per hundred thousand by weight
d	average depth in central regions of the channel
d_x	mean hydraulic depth = A/W_s
D	grain size sieve diameter based on areal grid surface sample
D_{50N}	median grain size diameter based on sieve analysis by number of stones.
D_{50W}	median grain size diameter based on sieve analysis by weight
F_b	bed factor = V^2/d
F_{bo}	zero bed factor
Fr	Froude Number
F_s	side factor = V^3/b
g	acceleration due to gravity
k_s	Nikuradse grain size roughness
n	Mannings n
Q	discharge in cfs.
R	hydraulic radius
Re	Reynolds Number
S	water surface slope
V	mean velocity
V_{mc}	competent mean velocity
V_s	settling velocity
V_*	shear velocity = $(gRS)^{\frac{1}{2}} \simeq (gd_x S)^{\frac{1}{2}}$
W_s	water surface breadth

ABBREVIATIONS

A.G.U.	American Geophysical Union
A.S.C.E.	American Society of Civil Engineers
cfs.	cubic feet per second
Comm.	commission
D.N.A.N.R.	Department of Northern Affairs and National Recources.
D/S	downstream
D.W.R. (Alta)	Department of Water Resources, Province of Alberta.
Fig (s).	figure (s)
I.A.H.R.	International Association for Hydraulic Research
lt.	left
mm.	millimeter (s)
P.F.R.A.	Prairie Farm Rehabilitation Administration
Proc.	proceedings
Ref. (s)	reference (s)
rt.	right
Sta.	station
Trans.	Transactions
U/S	upstream
U.S.G.S.	United States Geological Survey
W.E.	water's edge
W.L.	water level
X-section	cross-section

APPENDIX B

TABLES

TABLE B-I

SUMMARY OF COLORED ROCK RECOVERY

DRYWOOD CREEK

STATION	6"	5"	4"	3"	2"	1½"	1"	3/4"	1/2"	3/8"	DISTANCE (Ft.)	#ROCKS	AVE. DISTANCE (Ft.)
12+30	1	5	7	7	1	5	2	1	2	2	0	33	0
12+75	1	2	5	6	15	15	14	5	2	1	40	66	75
12+85- 13+10	1	1	10	22	38	34	50	22	27	8	70	213	
13+50- 15+25		2	2		7	8	9	4			210	32	495
15+50- 17+50				4	8	8	10	5			420	35	
18+00- 21+00			1	2	3	6	2	8	7		720	29	
27+00- 28+00		1		2	3	8	13	5	2	1	1520	35	2150
28+50- 35+00				5	1	10	1	2	2		1945	21	
35+00- 40+00					5	6	7	2	5		2520	25	
45+00						1	2				3270	3	3950
50+50						2	3	1	1		3820	7	
52+50						5	3		1		4020	9	
53+50								1			4120	1	
55+00- 57+00					1	5	6	2	2		4370	16	
57+25							1		1		4495	2	5200
59+25						4			1		4695	5	
60+75						2					4845	2	
66+00						1	4	1			5370	6	
68+00							1				5570	1	
70+50- 71+50						4	3	1			5870	8	
73+50- 75+00						1	3				6195	4	7500
79+50- 83+00						1	3				6895	4	
92+00- 95+00						2	1				8120	3	
96+00-104+00						2	1	1			8770	4	

ELBOW RIVER

STATION	6"	5"	4"	3"	2"	1½"	1"	3/4"	1/2"	3/8"	DISTANCE (Ft.)	#ROCKS	AVE. DISTANCE (Ft.)
44+00- 45+00				1	11	38	85	44	18		1250	197	1250
46+00- 47+00				1	6	34	123	43	20		1450	227	1450
48+00- 50+00 (Shallow channel)						26	145	111	76	9	1700	367	1700
48+00- 50+00 (Deep channel)				2	7	13	70	45	30		1700	167	1700

TABLE B-II

TABLE OF ANNUAL MAXIMUM DAILY DISCHARGES

River	Period of Records	Drainage Area in Sq. Miles	Discharge in C.F.S.			Return Period in Years
			Median	Maximum	Minimum	
Castle near Beaver Mines	1945-1964	319	4500	12800 18400*	2320	2 21.75 1.05
Sheep at Bucks Ranch	1951-1964	176	1500	4370 12000*	740	2 14.7 1.073
Elbow at Bragg Creek	1936-1964	306	1550	7060 7510*	620	2 30.1 1.035
Drywood near Twin Butte	1935-1964	11.8	190	770 970*	66	2 31.3 1.032

* Instantaneous Discharge

TABLE B-III

SUMMARY OF GRAVEL SAMPLES
(BY NUMBER IN FEET)

NOTATION: Example CA-4-T

First letters define the river
The number is the sample number
Last letter indicates type of sample
Sample types - W - Wolman method by picking stones under one toe
T - Tape sample above water surface
R - Random sample over a given area
A - Surface grid sample
S - Shovel-full at a time

CASTLE RIVER

SAMPLE	LOCATION	D_{50}	b_{50}	D_{65}	b_{65}	D_{90}	b_{90}
DCCA-1-T	Acr. old channel	.24		.31		.53	
DCCA-2-T	Outside bend old channel	.36		.48		1.00	
CA-4-T	Sta. 104+50-105+50 Rt. bank @ W.E.	.19		.21		.55	
CA-10-T	Sta. 127+00-128+00 Gravel ridge	.29		.37		.57	
CA-11-T	Sta. 136+50-137+00 Pt. bar @ W.E.	.19		.24		.38	
CA-12-W	Sta. 136+75 Mid-channel	.09		.23		.37	
CA-13-T	Sta. 84+00 Across bar	.11		.14		.24	
CA-14-T	Sta. 83+00- 85+00 Mid. of bar	.11		.13		.22	
CA-15-T	Sta. 20+00- 21+00 Rt. bank @ W.E.	.18		.24		.48	
CA-16-W	Sta. 20+00 Across channel	.22		.28		.45	
CA-17-T	Sta. 20+00- 21+00 Point bar	.092		.11		.18	
CA-18-T	Sta. 2+00- 3+00 Rt. bank @ W.E.	.22		.24		.45	

TABLE B-III (Continued)

CA-19-T	Sta. 2+50- 3+50 Rt. bank 2' up	.14		.18		.28	
CA-20-T	Sta. 2+50- 3+50 Rt. bank 4' up	.25		.29		.43	
CA-24-T	Sta. 62+00- 63+00 Rt. bank @ W.E.	.13		.15		.25	
CA-25-T	Sta. 107+35- 108+35 Rt. bank @ W.E.	.08		.09		.13	
CA- 3-R	Sta. 105+00 Rt. bank		1.12		1.18		1.40
	SHEEP RIVER						
SH- 1-W	Sta. 94+60- 94+85 Bar	.062		.073		.11	
SH- 2-W	Sta. 94+64 Across channel	.042		.056		.11	
SH- 3-A	Sta. 94+15 Bar	.063		.073		.10	
SH- 4-A	Sta. 96+50 Bar	.067		.08		.12	
SH- 5-W	Sta. 96+50 Across channel	.039		.053		.11	
SH- 6-R	Sta. 93+00 Bar	.038		.047		.075	
SH- 7-W	Sta. 93+50- 94+00 Lft. bank @ W.E.	.088		.12		.22	
SH- 8-T	Sta. 92+00- 92+50 Lft. bank @ W.E.	.13		.17		.28	
SH- 9-T	Sta. 92+00- 92+50 Bar	.11		.13		.22	
SH-10-T	Sta.137+00- 138+00 Bar @ W.E.	.13		.16		.28	
SH-11-T	Sta.137+00- 138+00 Top of bar	.12		.14		.23	
SH-12-W	Sta.135+50 Across channel	.082		.10		.16	
SH-13-T	Sta.135+00- 135+50 Top of bar	.13		.16		.24	
SH-14-T	Sta.134+00- 135+00 Rt. bank @ W.E.	.098		.16		.19	
SH-15-T	Sta.133+00- 133+50 Rt. bank	.13		.19		.29	

TABLE B-III (Continued)

SH-16-W	Sta. 132+60	.15	.26	.30
SH-17-T	Sta. 127+00			
	Point bar	.20	.26	.47
SH-18-T	Sta. 123+50- 124+00			
	Top of bar	.21	.26	.43
SH-19-T	Sec. 2 TP. 20 Rg. 3			
	Lft. W.E.	.22	.25	.44
SH-20-T	3/4 mi. E. Turner Valley			
	Top of bar	.11	.13	.18
SH-21-T	3/4 mi. E. Turner Valley			
	Rt. bank @ W.E.	.14	.18	.28

ASSUMED ACTIVE MATERIAL AT HIGH STAGES

	Sta. 3+50	.91	1.00	1.40
	Sta. 7+00	1.05	1.18	1.37
	Sta. 11+00	.76	.82	1.20
	Sta. 12+50- 13+00	1.60	1.70	2.70
	Sta. 25+50- 27+50	1.35	1.63	2.15
	Sta. 61+50	1.05	1.15	1.30
	Sta. 110+00	1.07	1.10	1.47
	Sta. 122+00	1.25	1.40	1.50
	Tp. 20 Rg. 3 S.E. ¼	1.00	1.05	1.35

ELBOW RIVER

E- 1 -T	Sta. -4+50- -5+50			
	Rt. bank @ W.E.	.22	.29	.57
E- 2a-T	Sta. -14+00- -15+00			
	Rt. bank 2' up	.17	.21	.38
E- 2b-T	Sta. -14+00- -15+00			
	Rt. bank @ W.E.	.31	.38	.61
E- 3 -T	Sta. 89+60- 90+60			
	Rt. bank @ W.E.	.31	.42	.88
E- 4 -A	Sta. 90+60			
	Rt. bank 1' above W.L.	.10	.13	.24
E- 4 -A	Sta. 90+60			
	Rt. bank 2' above W.L.	.11	.14	.22
E- 6 -A	Sta. 90+60			
	Rt. bank 1½' above W.L.	.12	.15	.27
E- 7 -A	Sta. 90+60			
	Rt. bank 2½' above W.L.	.10	.12	.19
E- 8a-W	Sta. 8+00			
	Across channel	.15	.19	.29

TABLE B-III (Continued)

E- 8b-W	Sta. 8+00						
	Across channel	.15		.19		.29	
E- 9 -T		.12		.15		.25	
E2- 1 -A	¼ mi. D/S from 117+00						
	Top of bar	.18		.22		.33	
E2- 2 -R	¼ mi. D/S from 117+00						
	Top of bar		1.07		1.25		1.50
E2- 3 -T	Sta. 91+00- 92+00						
	Lft. bank @ W.E.	.23		.32		.71	
E2- 4 -T	Sta. 93+00- 94+00						
	Top of bar	.12		.17		.28	
E2- 5 -W	Sta. 92+00						
	Across channel	.16		.20		.31	
E2- 6 -R	Sta. 113+00						
	Large active material		.98		1.10		1.38
E2- 7 -T	Sta. 90+16- 91+16						
	Rt. bank 1½' above W.L.	.28		.34		.57	
E2- 8 -T	8 mi. D/S from Bragg Cr.	.13		.16		.28	
E2- 9 -T	¼ mi. D/S from						
	Twin Bridges Bridge	.13		.17		.26	

DRYWOOD CREEK

DR-22-W	Sta. 6+35						
	Across channel		.51		.60		.82
DR-23-W	Sta. 6+82						
	Across channel		.40		.48		.66
DR-16-W	Sta. 19+25- 19+15						
	Across channel	.27		.31		.43	
DR-13a-W	Sta. 19+75- 20+00						
	Submerged bar	.079		.09		.12	
DR-13b-W	"						
	"	.083		.10		.14	
DR-13c-A	"						
	"	.043		.053		.083	
DR-14-T	Sta. 20+50- 21+00						
	Lft. bank @ W.E.	.17		.23		.46	
DR-15-T	Sta. 20+50- 21+50						
	Rt. bank @ W.E.	.23		.26		.38	
DR-12-T	Sta. 28+50- 29+00						
	High dry channel	.13		.16		.27	
DR-17-W	Sta. 0+00						
	Across channel		.43		.55		.76

TABLE B-III (Continued)

DR-32-W	Sta. 33+60						
	Across channel		.37		.44		.65
DR-35-W	Sta. 41+25- 42+00						
	Lft. bank @ W.E.		.68		.79		1.10
DR- 1-W	Sta. 45+00- 45+50						
	Channel bed	.25		.32		.53	
DR-39-W	Sta. 40+75- 51+50						
	Bar, mid-stream	.27		.31		.48	
DR-40-T	Sta. 56+25- 56+75						
	Bar, mid-stream	.29		.33		.42	
DR-41-T	Sta. 55+75- 56+75						
	1' above W.L.	.13		.15		.25	
DR- 9-T	Sta. 110+00-110+50						
	Rt. bank @ W.E.	.11		.14		.24	
DR-10-W	Sta. 110+00-110+50						
	Channel bed	.25		.31		.47	
DR- 8-T	Sta. 114+27-115+27						
	Top lft. side of bar	.15		.18		.29	
DR- 4-T	Sta. 119+25-120+25						
	Lft. bank @ W.E.	.15		.19		.34	
DR-11-W	Sta. 119+00-120+00						
	Channel bed	.35		.45		.90	
DR- 6-W	Sta. 120+50						
	Across channel	.092		.11		.17	
DR- 7-W	Sta. 120+60						
	Across channel	.046		.063		.13	
	Sta. 122+00						
	Top of bar	.31		.33		.38	

ASSUMED ACTIVE MATERIAL FOR LOW DISCHARGES

DR- 2-R	Sta. 125+00			
	Across submerged bar	.068	.083	.12
DR-19-S	Sta. 2+10			
	Across channel	.067	.085	.14
DR-20-S	Sta. 2+45			
	Above beaver dam	.077	.096	.16
DR-36-S	Sta. 50+50			
	Across channel	.15	.21	.33
DR-43-S	Sta. 57+60			
	Across channel	.063	.088	.18
DR-44-S	Sta. 121+50	.068	.096	.18
DR-45-S	Sta. 122+50	.083	.11	.20
DR-46-S	Sta. 123+50	.063	.079	.14

TABLE B-III (Continued)

DR-47-S	Sta. 124+50	.052	.075	.16
DR-48-S	Sta. 125+50	.023	.035	.10
DR-49-S	Sta. 126+50	-	.023	.05
DR-50-S	Sta. 126+50	.033	.046	.10

TABLE B-IV

SAMPLING METHOD - TEST RESULTS

PERCENT RETAINED BY NUMBER

Sheep River

Sample	D_{84}	D_{50}	D_{16}	$\frac{D_{84}}{D_{16}}$[a]	Remarks
Coarse Material (Site "A")					
SHX-1	-	2.9	0.90	-	(tape)
SHX-2	1.80	.96	.59	3.05	Combined (grid surface)[b]
SHX-3	5.0	2.65	1.20	4.16	(Wolman)
SHX-4	0.90	0.60	0.47	1.92	(grid to deepest surface rock)
Fine Material (Site "B")					
SHX-5	1.42	0.81	0.51	2.78	(tape)
SHX-6	1.66	1.0	0.69	2.41	(Wolman)
SHX-7	1.06	0.67	-	-	Combined (grid, surface)[b]
SHX-8	0.90	0.61	-	-	(Grid to deepest surface rock)

Castle River

Sample	D_{84}	D_{50}	D_{16}	$\frac{D_{84}}{D_{16}}$[a]	Remarks
CA-5	4.10	2.05	1.04	3.94	Sampler 'A' (tape)
CA-6	3.70	2.10	1.04	3.56	Sampler 'B' (tape)
CA-8	3.70	2.50	1.58	2.34	Sampler 'B' (Wolman)
CA-9	3.70	2.20	1.17	3.16	Sampler 'A' (Wolman)
CA-10	2.10	1.10	0.64	3.28	(Grid, surface)
CA-5+6	3.90	2.10	1.07	3.62	(Combined samples)
CA-8+9	3.70	2.40	1.30	2.85	(Combined samples)
CA-10	2.10	1.10	0.64	3.28	(Grid, surface)

[a] Logarithmic Standard Deviation $2\,\sigma_{\log\ D} = \log\left(\frac{D_{84}}{D_{16}}\right)$

[b] Three grid surface samples taken at the center and ends of the survey tape using 2' square grids.

TABLE B-V

SAMPLING METHOD - TEST RESULTS

PERCENT RETAINED BY WEIGHT

Sheep River

Sample	D_{84}	D_{50}	D_{16}	$\frac{D_{84}}{D_{16}}$ [a]	Remarks
Coarse Material (Site "A")					
SHX-1	-	-	5.60	-	(tape)
SHX-2	-	-	3.15	-	Combined (grid, surface)[b]
SHX-3	-	5.65	3.55	-	(Wolman)
SHX-4	-	-	2.00	-	(Grid to deepest surface rock)
Fine Material (Site "B")					
SHX-5	2.95	1.87	1.18	2.50	(tape)
SHX-6	2.95	2.00	1.10	2.68	(Wolman)
SHX-7	3.51	1.37	0.86	4.07	Combined (grid, surface)[b]
SHX-8	1.53	0.73	-	-	(Grid to deepest surface rock)
Castle River					
CA-5	-	4.50	3.15	-	Sampler 'A' (tape)
CA-6	5.90	4.35	3.00	1.97	Sampler 'B' (tape)
CA-8	4.80	3.70	2.65	1.81	Sampler 'B' (Wolman)
CA-9	5.90	4.50	2.90	2.02	Sampler 'A' (Wolman)
CA-10	5.10	3.90	1.75	2.92	(Grid surface)
CA-5+6	5.90	4.40	3.10	1.90	Combined samples
CA-8+9	5.40	4.00	2.75	1.96	Combined samples
CA-10	5.10	3.90	1.75	2.92	(Grid surface)

[a] Logarithmic Standard Deviation $2\,\sigma_{\log\ D} = \log\left(\frac{D_{84}}{D_{16}}\right)$

[b] Three grid surface samples taken at the center and ends of the survey tape using 2' square grids.

TABLE B-VI

CROSS-SECTION DATA AT REPRESENTATIVE DISCHARGE

CASTLE RIVER @ 7000 CFS.

Section	A $ft.^2$	V ft/sec	S $x10^{-3}$	d ft.	W_s ft.	d_x ft.	Remarks
3+25	606	11.5	1.6	3.7	206	2.95	
8+25	714	9.82	.5	6.0	210	3.39	
20+00	806	8.69	4.5	3.8	243	3.31	
31+00	932	7.52	3.0	6.5	183	5.09	
48+00	854	8.20	3.8	4.5	209	4.08	
58+00	755	9.27	3.0	5.7	169	4.46	
66+25	915	7.65	7.3	4.5	250	3.66	
76+00	996	7.03	2.0	6.0	200	4.98	
84+00	1132	6.19	9.7	5.1	280	4.04	
90+00	1428	4.91	3.5	4.5	335	4.26	
104+00	1110	6.30	2.0	4.8	296	3.78	
108+00	780	8.98	5.0	5.0	175	4.45	
112+00	564	12.4	1.0	4.2	166	3.4	
118+50	805	8.69	6.0	4.9	200	4.02	
127+00	1420	4.93	7.5	7.7	230	6.18	
138+00	594	11.8	-	4.0	207	2.86	

SHEEP RIVER @ 3500 CFS.

Section	A $ft.^2$	V ft/sec	S $x10^{-3}$	d ft.	W_s ft.	d_x ft.	Remarks
2+00	250	14.0	2.4	3.0	89	2.81	
7+00	169	20.7	-	2.2	84	2.02	
26+75	1021	3.42	-	6.4	162	6.31	
40+00	450	7.78	-	5.0	99	4.55	
59+00	299	11.7	-	3.4	97	3.08	
65+00	342	10.2	-	5.9	90	3.80	
77+00	385	9.1	6.7	4.2	105	3.67	
85+00	555	6.31	6.0	6.6	114	4.86	
92+25	706	4.96	9.6	6.3	133	5.31	
93+00	1022	3.43	7.4	7.5	164	6.24	
93+60	495	7.08	7.0	5.5	105	4.71	
94+64	370	9.46	8.6	3.6	118	3.14	
96+50	550	6.36	7.5	4.8	130	4.24	
103+75	724	4.84	5.0	5.6	136	5.33	
118+50	511	6.85	5.3	4.1	127	4.02	
123+50	514	6.83	-	5.8	121	4.25	
127+00	916	3.82	9.0	6.2	174	5.26	
132+60	680	5.15	-	6.1	146	4.65	
133+50	600	5.84	6.8	5.8	134	4.48	
134+50	650	5.39	6.0	6.4	116	5.61	
135+50	749	4.68	8.0	6.0	147	5.09	
137+00	619	5.65	10.7	5.7	140	4.32	
138+00	556	6.30	-	4.3	139	4.0	

TABLE B-VI (CONTINUED)

CROSS-SECTION DATA AT REPRESENTATIVE DISCHARGE

ELBOW RIVER @ 3000 CFS.

Section	A ft.^{2}	V ft/sec	S x10^{-3}	d ft.	W_s ft.	d_x ft.	Remarks
-4+10	604	4.73	-	4.5	170	3.66	95% of Q
8+00	799	3.76	-	2.7	290	2.91	100% of Q
10+90	560	4.83	-	3.0	200	2.96	90% of Q
29+00	414	5.08	-	3.1	164	2.67	70% of Q
32+05(rt)	397	4.91	-	3.7	115	3.66	65% of Q
32+05(lt)	211	4.26	-	2.5	90	2.48	30% of Q
40+00	730	3.70	-	3.8	190	4.06	90% of Q
41+30	520	5.19	-	3.5	157	3.50	90% of Q
45+55	485	5.26	-	3.5	160	3.20	85% of Q
64+48(rt)	372	5.65	-	2.6	160	2.46	70% of Q
64+48(lt)	108	2.78	-	2.0	70	1.63	10% of Q
81+60	516	3.49	-	2.5	265	2.06	60% of Q
92+00	373	7.24	-	3.8	110	3.59	90% of Q
95+00	466	5.80	-	4.2	135	3.66	90% of Q
103+00	581	5.16	-	3.6	195	3.16	100% of Q
113+00	615	4.88	-	3.8	175	3.72	100% of Q

DRYWOOD CREEK @ 350 CFS.

Section	A ft.^{2}	V ft/sec	S x10^{-3}	d ft.	W_s ft.	d_x ft.	Remarks
A	63.3	5.54	-	2.3	32	1.98	
N	70.0	5.00	-	1.5	44	1.59	
14+50	82.5	4.25	-	2.2	43	1.92	
28+70	80.6	4.34	-	3.4	28	2.88	
0+00	57.6	6.08	-	1.8	38	1.52	
6+35	53.1	6.60	-	1.6	36	1.47	
7+75	62.7	5.58	-	2.1	41	1.53	
21+00	51.8	6.75	-	1.8	35	1.48	
30+10	91.5	3.82	-	3.5	30	3.06	
33+60	94.1	3.72	-	2.8	43	2.19	
38+12	103	3.40	-	2.5	52	1.98	
52+90	121	2.89	-	2.9	53	2.28	
56+50	64.4	5.44	-	1.8	42	1.54	
57+60	98.4	3.56	-	1.8	56	1.76	
70+85	106	3.30	-	2.2	53	2.00	
72+75	50.8	6.90	-	1.8	30	1.69	
80+50	63.8	5.48	-	2.2	31	2.06	
98+50	93.8	3.73	-	2.7	38	2.47	
104+50	164	2.13	-	3.2	55	2.98	
119+65	80	4.38	-	1.9	39	2.04	
123+00	84.6	4.14	-	1.8	46	1.84	

TABLE B-VII

AVERAGE RIVER DATA FOR FLOWS AT REPRESENTATIVE DISCHARGE

River	Q cfs.	V ft/sec	S $\times 10^{-3}$	d ft.	W_s ft.	d_x ft.	D_{50} ft.	D_{65} ft.	D_{90} ft.	b_{50} ft.	b_{65} ft.	b_{90} ft.
Castle R. near Beaver Mines	7000	8.37	3.74[a]	5.06	222	4.06	.18	.23	.41			
(MATERIAL ACTIVE OR EXPOSED AT 18,000 CFS.)										1.12	1.18	1.40
Sheep R. near Buck Ranch	3500	7.11	6.92	5.23	125	4.26	.11	.15	.23			
(APPARENTLY ACTIVE MATERIAL FOR HIGHER DISCHARGES)										1.12	1.23	1.60
Elbow R. near Bragg Cr.	3000[b]	4.80	7.05[a]	3.30	165	3.09	.17	.22	.39			
(APPARENT ACTIVE MATERIAL FOR Q = 4500 CFS.)										1.03	1.18	1.44
Drywood Cr. near Twin Butte	350	5.00	11.1	2.28	41	2.01	.18	.22	.34			
(LARGE MATERIAL FORMING BED PAVEMENT)										.48	.57	.80
(ACTIVE BED MATERIAL FOR LOW DISCHARGES)							.068	.085	.16			

[a] Water surface slope from profile at low stages.

[b] Considering the over-bank spillage the average Q used to get the geometry of the channel section comes out to be about 2300 cfs.

TABLE B-VIII

DATA ON SAN LUIS VALLEY CANAL TEST SECTIONS

AT FULL SUPPLY (REF. 7)

							BY WEIGHT		
Section	Q cfs.	V ft/sec	S $\times 10^{-3}$	d ft.	W_s ft.	d_x ft.	D_{50} ft.	D_{65} ft.	D_{90} ft.
1	1500	5.88	2.80	4.87	73	3.50	.32	.40	.70
2	668	5.83	3.76	2.81	55	2.08	.26	.31	.50
4	768	6.53	3.59	3.11	48	2.54	.26	.33	.53
5	448	5.82	3.68	2.50	40	1.92	.18	.20	.28
6	159	4.59	2.95	1.88	21.7	1.60	.14	.16	.20
7	95.6	4.36	2.90	1.73	15.9	1.38	.14	.15	.18
8	46	3.00	3.16	.96	19.2	.80	.13	.16	.26
9	-	-	-	-	-	-	.13	.15	.19
10	16.6	2.90	9.65	.60	11.1	.515	.21	.26	.40
11	203	3.88	2.35	1.88	32.3	1.62	.17	.19	.24
12	128	4.00	2.43	1.77	21.9	1.46	.12	.14	.17
14	110	3.29	1.36	2.00	21.4	1.56	.07	.084	.12
15	477	4.84	1.99	3.05	39.4	2.50	.17	.20	.28
16	-	-	-	-	-	-	.17	.21	.32
17	531	5.51	2.74	2.60	41	2.35	.13	.14	.17
18	235	3.80	.80	2.94	25	2.48	.073	.081	.10

DATA FROM LABORATORY EXPERIMENTS (REF. 3)

Test									
2	1	2.10	9.9	.22	2.6	.183	.0197	.0295	.0459
3	1	2.27	12.4	.15	3.0	.147	.0197	.0295	.0459
4	2.25	2.57	6.25	.26	3.4	.258	.0197	.0295	.0459

TABLE B-VIII (CONTINUED)

DATA ON RIVERS IN CENTRAL B.C. (REF. 3)

Section	Q cfs.	V ft/sec	S $\times 10^{-3}$	d ft.	W_s ft.	d_x ft.	BY NUMBER		
							b_{50} ft.	b_{65} ft.	b_{90} ft.
Chilko R. at Henry's Crs.	5600	8.1	5.03	5.5	150	4.6	.47	.54	.83
Taseko R. below Taseko Lake	6400	8.0	2.9	6.2	150	5.3	.49	.63	1.0
Chilko R. at outlet of Chilko Lake	7000	4.0	.92	7.5	270	6.5	.37	.32	.58
Cariboo R. at Quesnel Forks	12000	9.6	4.19	8.5	190	6.6	.88	1.0	1.5
Quesnel R. at Lawless Creek	14800	11.4	6.33	8.0	200	6.5	.71	.87	1.3
Cariboo R. at outlet of Cariboo Lake	17000	6.1	1.92	13	260	10.8	.64	.83	1.1
Thompson R. below Kamloops Lake	135000	11.8	0.72	34	450	25.6	.58	.66	.88

APPENDIX C

FIGURES

FIG. C2-1

in back cover

FIG. C2-2

in back cover

CASTLE RIVER

LEGEND

CRETACEOUS

UPPER CRETACEOUS

☐ BELLY RIVER FORMATION

▨ WAPIAPI (UPPER ALBERTA) FORMATION

▭ BIGHORN (CARDIUM) FORMATION

▨ BLACKSTONE (LOWER ALBERTA) FORMATION

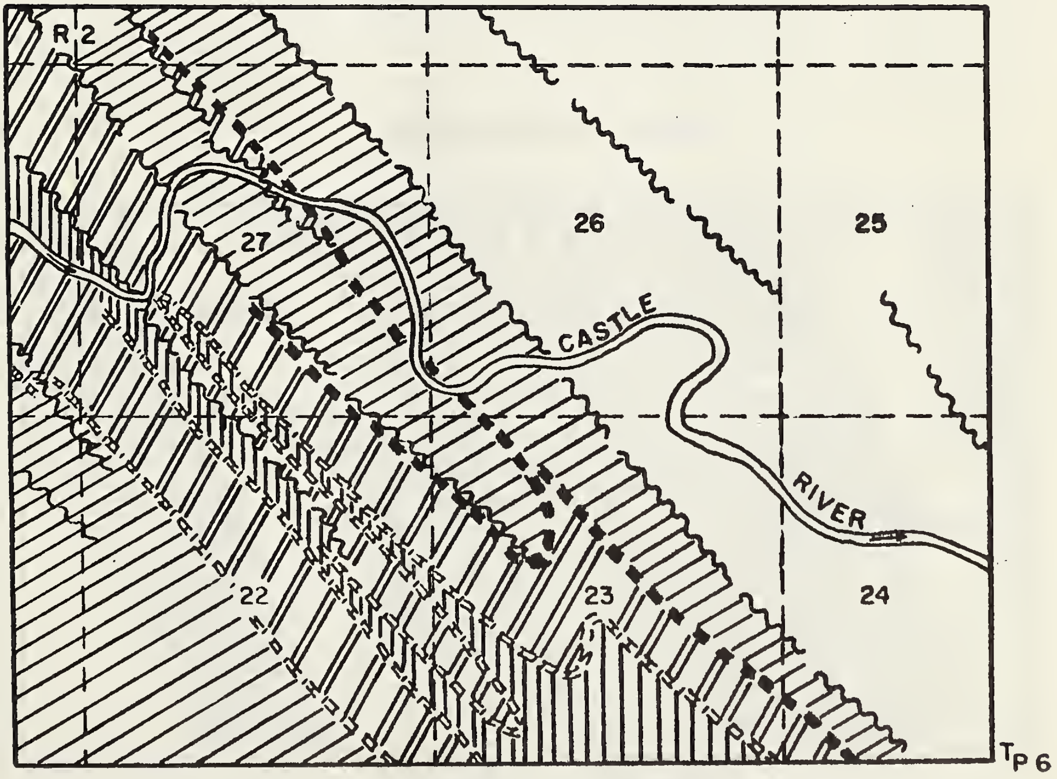
▨ CROWSNEST FORMATION

LOWER CRETACEOUS

▥ BLAIRMORE FORMATION

〰 FAULT

GEOLOGICAL MAP



SCALE 2" TO 1 MILE

FIG. C2-3

[illegible]

SHEEP RIVER

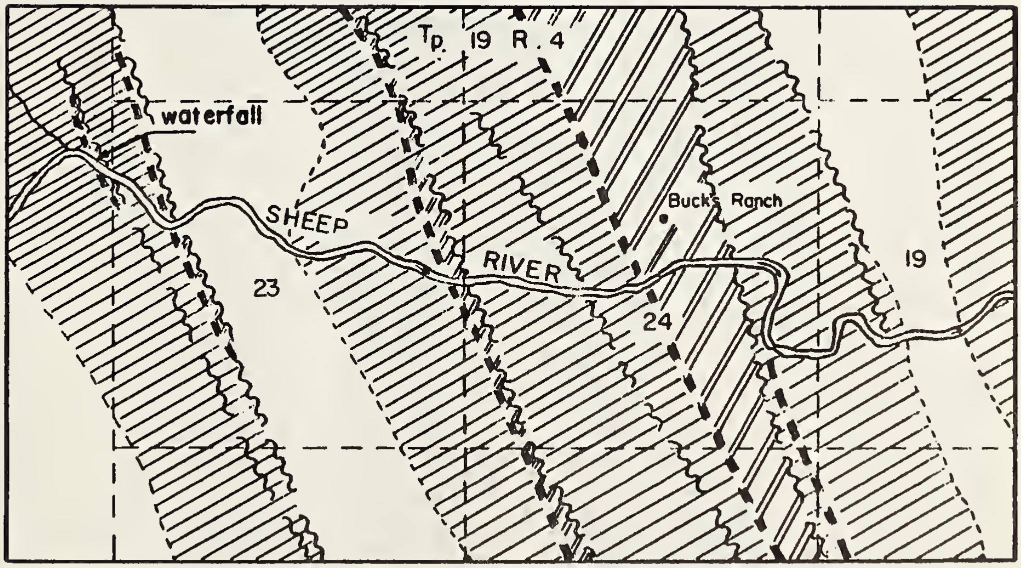
LEGEND

CRETACEOUS

UPPER CRETACEOUS

☐	BELLY RIVER FORMATION
▨	WAPIABI (UPPER ALBERTA) FORMATION
╍	BIGHORN (CARDIUM) FORMATION
▨	BLACKSTONE (LOWER ALBERTA) FORMATION
〰	FAULT

GEOLOGICAL MAP



SCALE 2" TO 1 MILE

FIG. C2-4

ELBOW RIVER

LEGEND

CRETACEOUS

UPPER CRETACEOUS

□ BELLY RIVER FORMATION

▨ WAPIABI (UPPER ALBERTA) FORMATION

▬ BIGHORN (CARDIUM) FORMATION

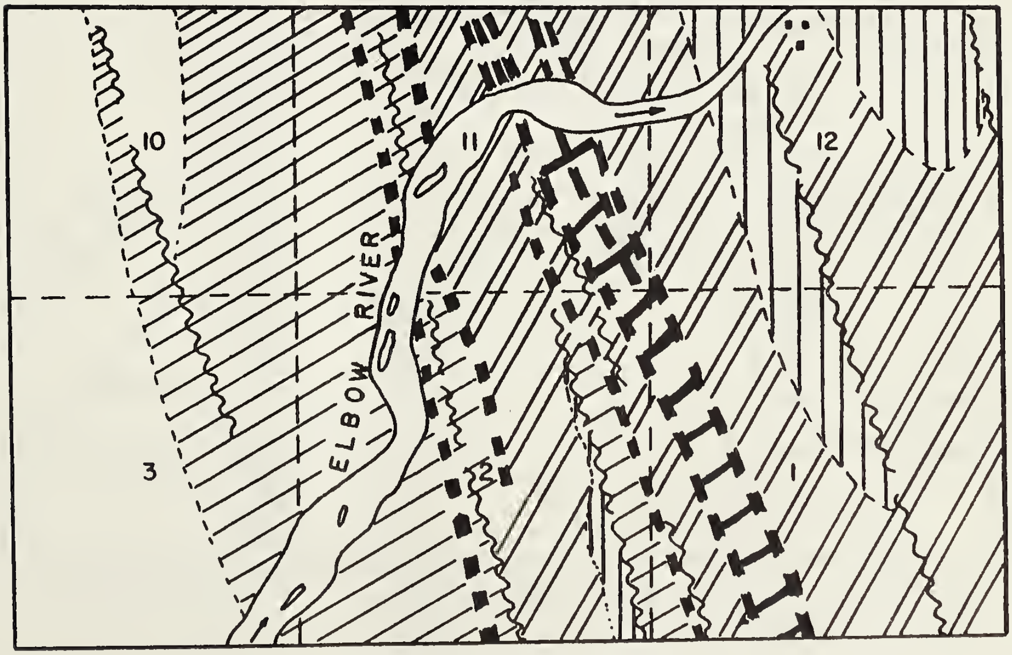
▨ BLACKSTONE (LOWER ALBERTA) FORMATION

LOWER CRETACEOUS

▥ BLAIRMORE FORMATION

∿ FAULT

GEOLOGICAL MAP



SCALE 2" TO 1 MILE

FIG. C2-5

DRYWOOD CREEK

LEGEND

CRETACEOUS

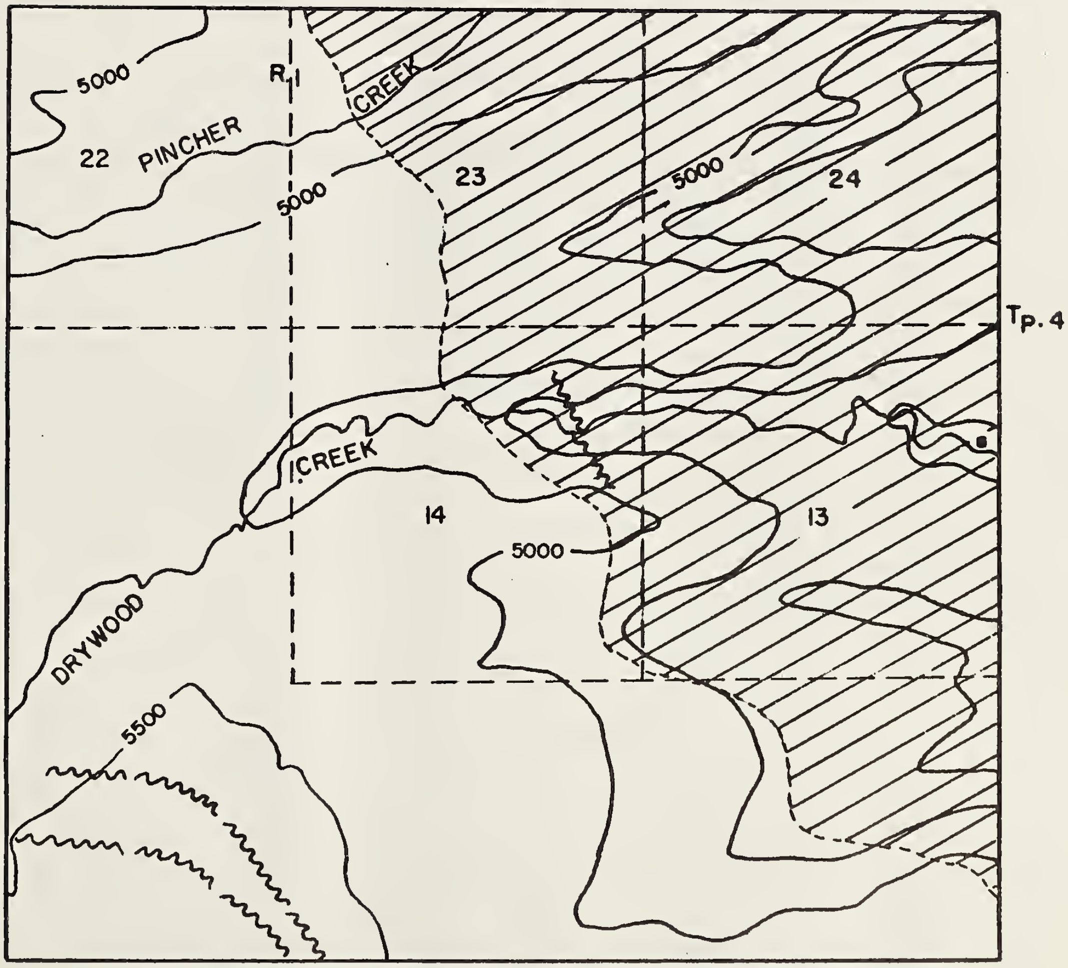
UPPER CRETACEOUS

☐ BELLY RIVER FORMATION

▨ WAPIABI (UPPER ALBERTA) FORMATION

〰 FAULT

GEOLOGICAL MAP



SCALE 2" TO 1 MILE

FIG. C2-6

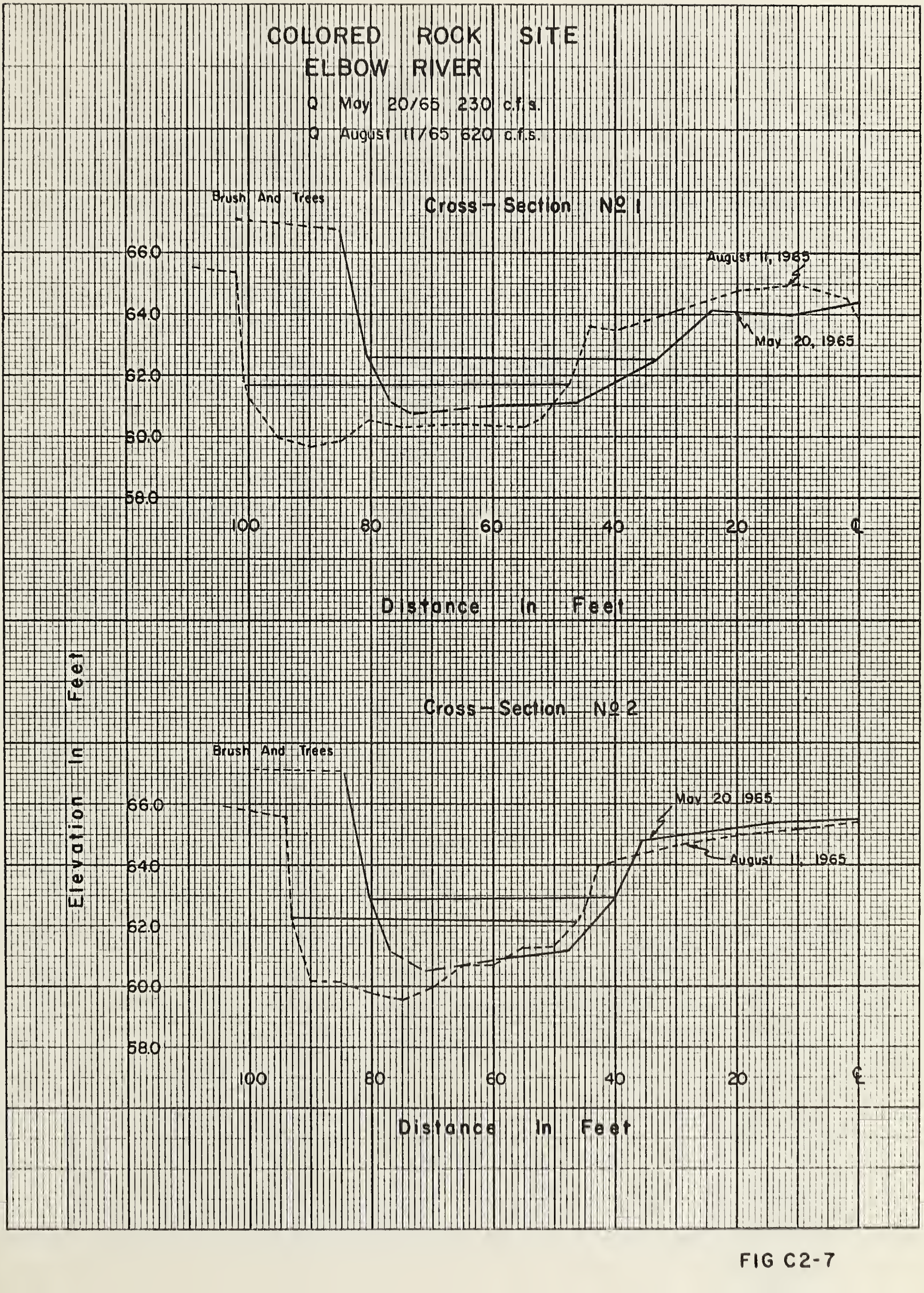

COLORED ROCK SITE
ELBOW RIVER
Q May 20/65 230 c.f.s.
Q August 11/65 620 c.f.s.
Cross-Section № 1
Brush And Trees
August 11, 1965
May 20, 1965
66.0
64.0
62.0
60.0
58.0
100
80
60
40
20
℄
Distance In Feet
Elevation In Feet
Cross-Section № 2
Brush And Trees
May 20 1965
August 11, 1965
66.0
64.0
62.0
60.0
58.0
100
80
60
40
20
℄
Distance In Feet

FIG C2-7

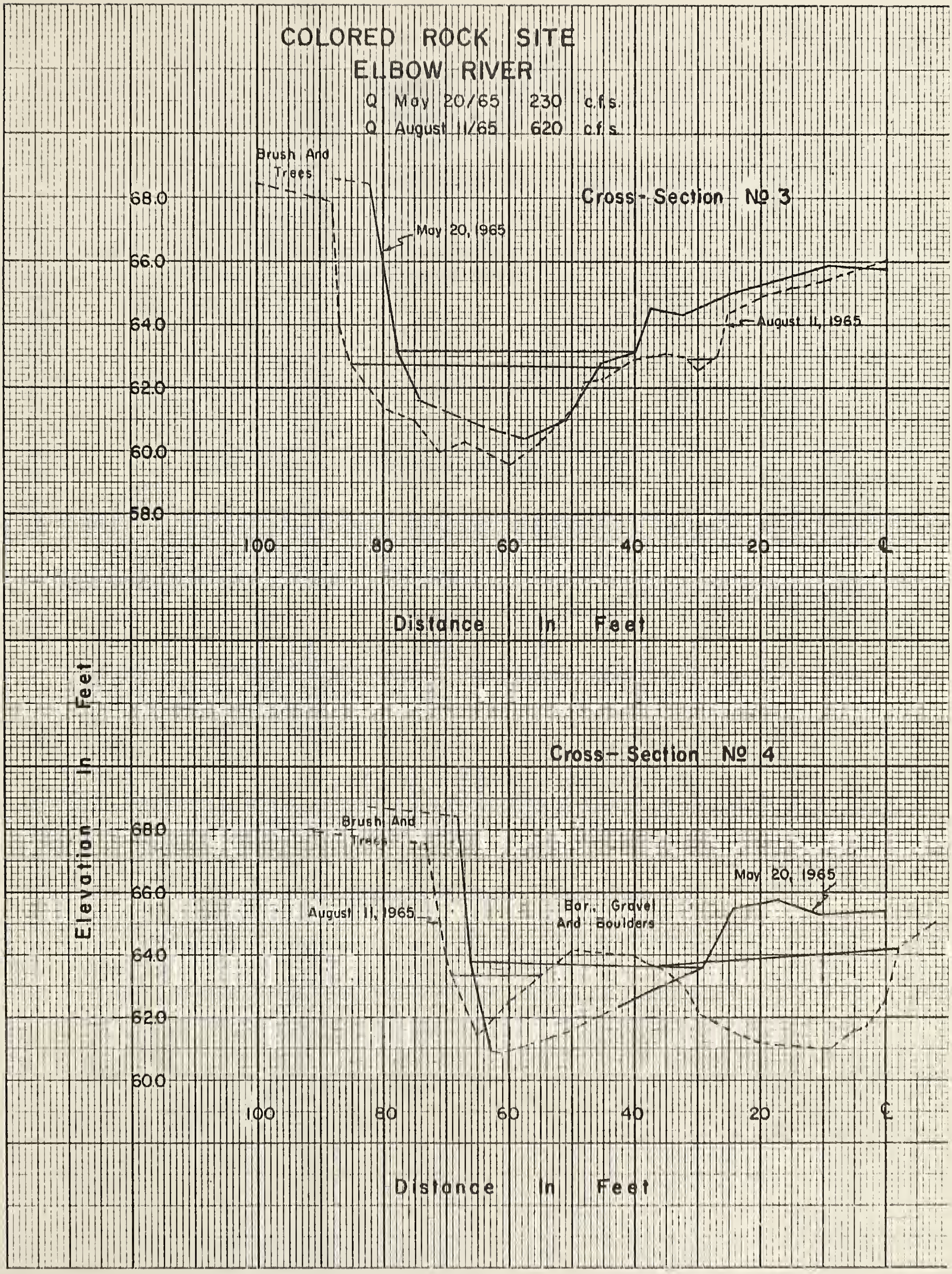
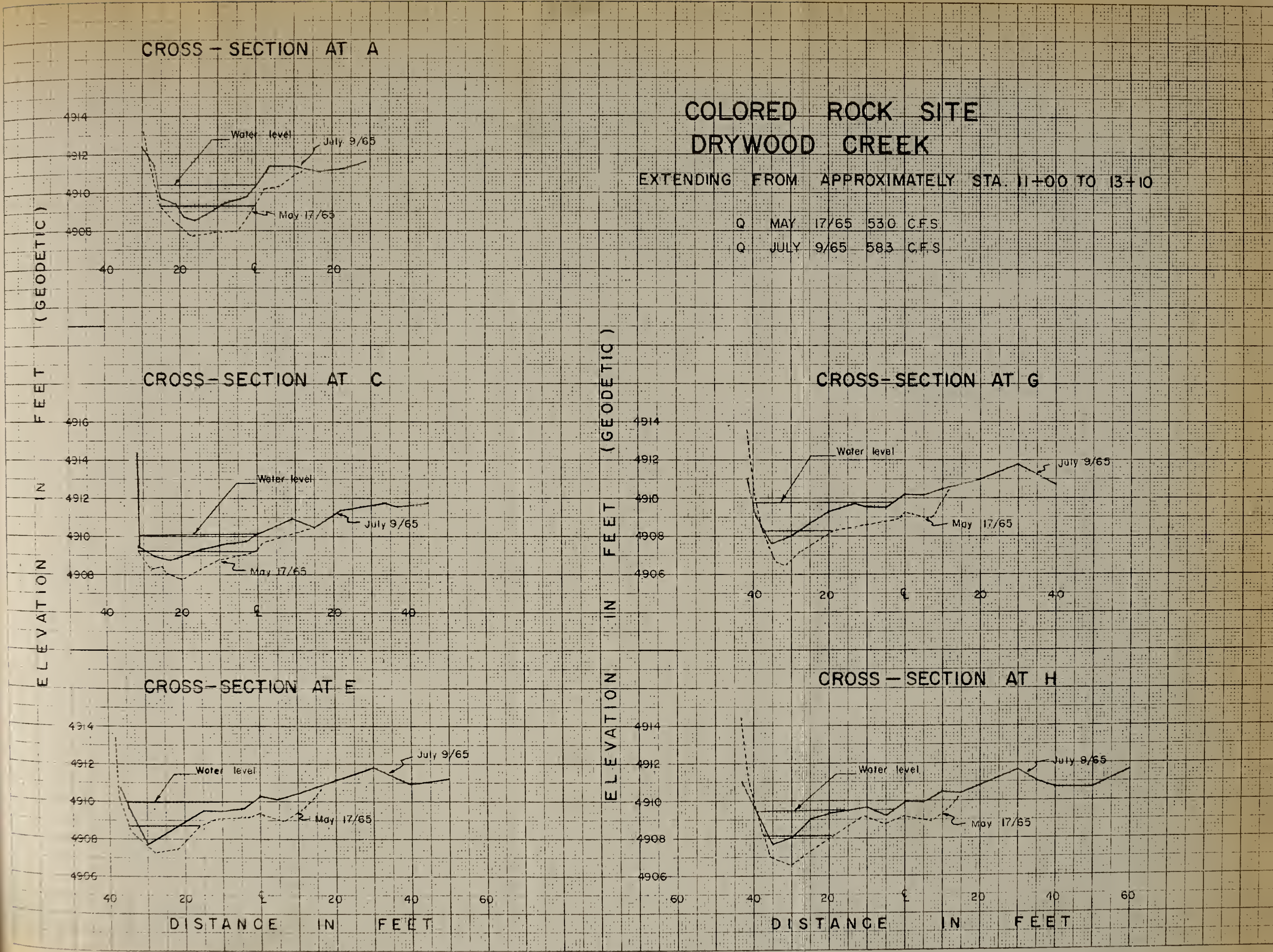

COLORED ROCK SITE
ELBOW RIVER
Q May 20/65 230 c.f.s.
Q August 11/65 620 c.f.s.
Brush And Trees
Cross-Section № 3
May 20, 1965
August 11, 1965
68.0
66.0
64.0
62.0
60.0
58.0
100
80
60
40
20
℄
Distance In Feet
Elevation In Feet
Cross-Section № 4
Brush And Trees
August 11, 1965
Bar, Gravel And Boulders
May 20, 1965
68.0
66.0
64.0
62.0
60.0
100
80
60
40
20
℄
Distance In Feet

FIG. C2-8

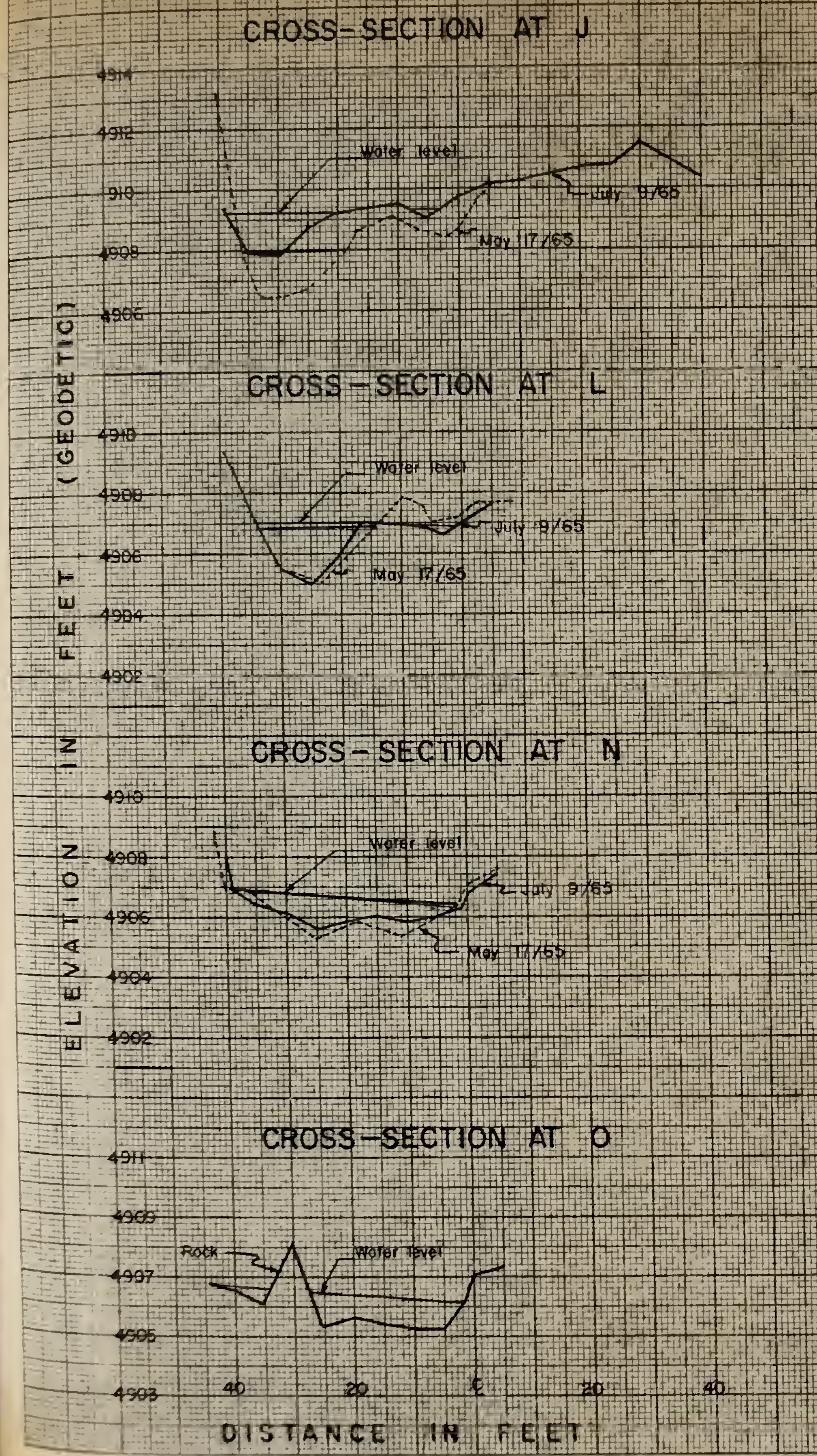


COLORED ROCK SITE
DRYWOOD CREEK

EXTENDING FROM APPROXIMATELY STA. 11+00 TO 13+10

Q MAY 17/65 530 C.F.S.
Q JULY 9/65 583 C.F.S.

FIG. C2-9



COLORED ROCK SITE

DRYWOOD CREEK

EXTENDING FROM APPROXIMATELY STA. 11+50 TO 13+10

Q MAY 17/65 530 C.F.S.

Q JULY 9/65 583 C.F.S.

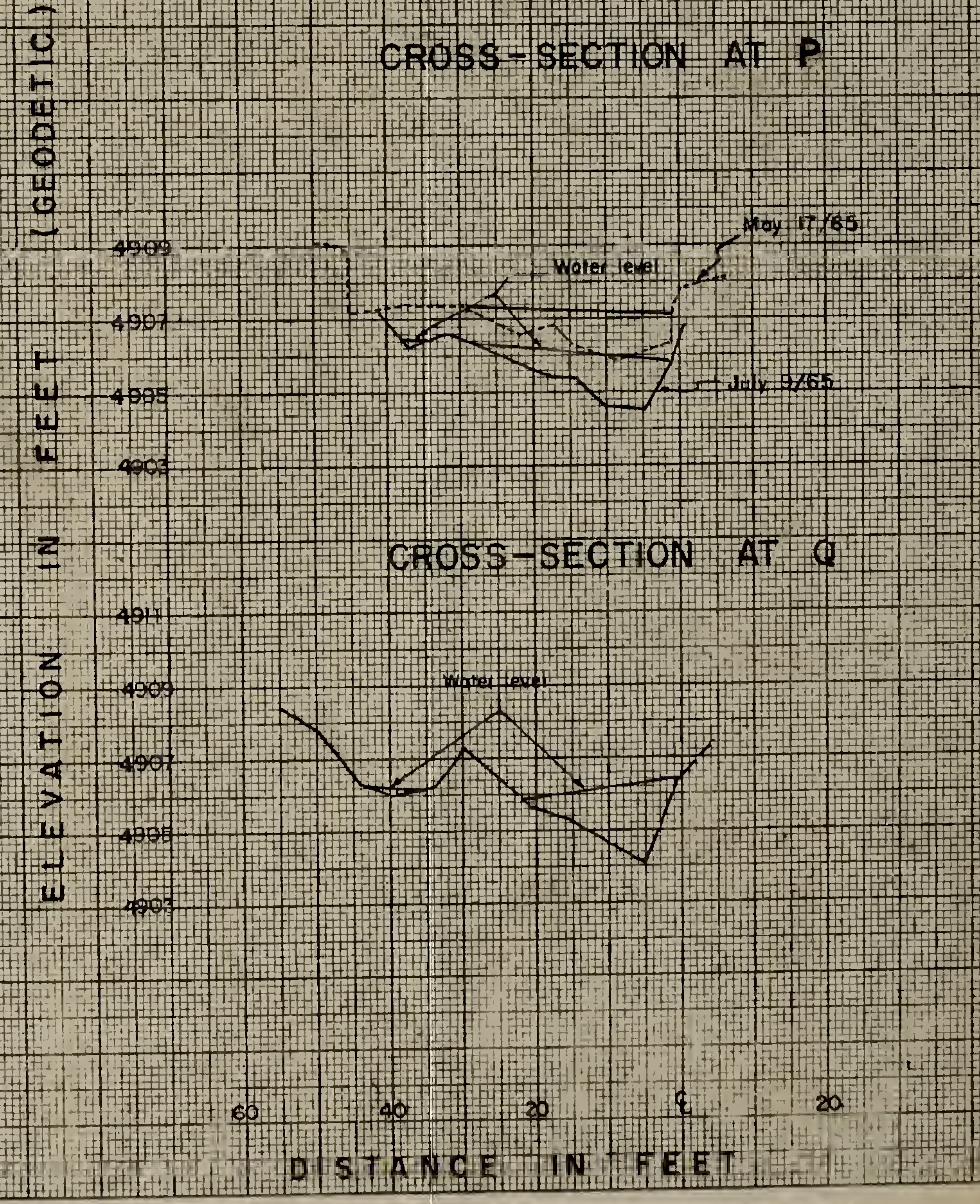
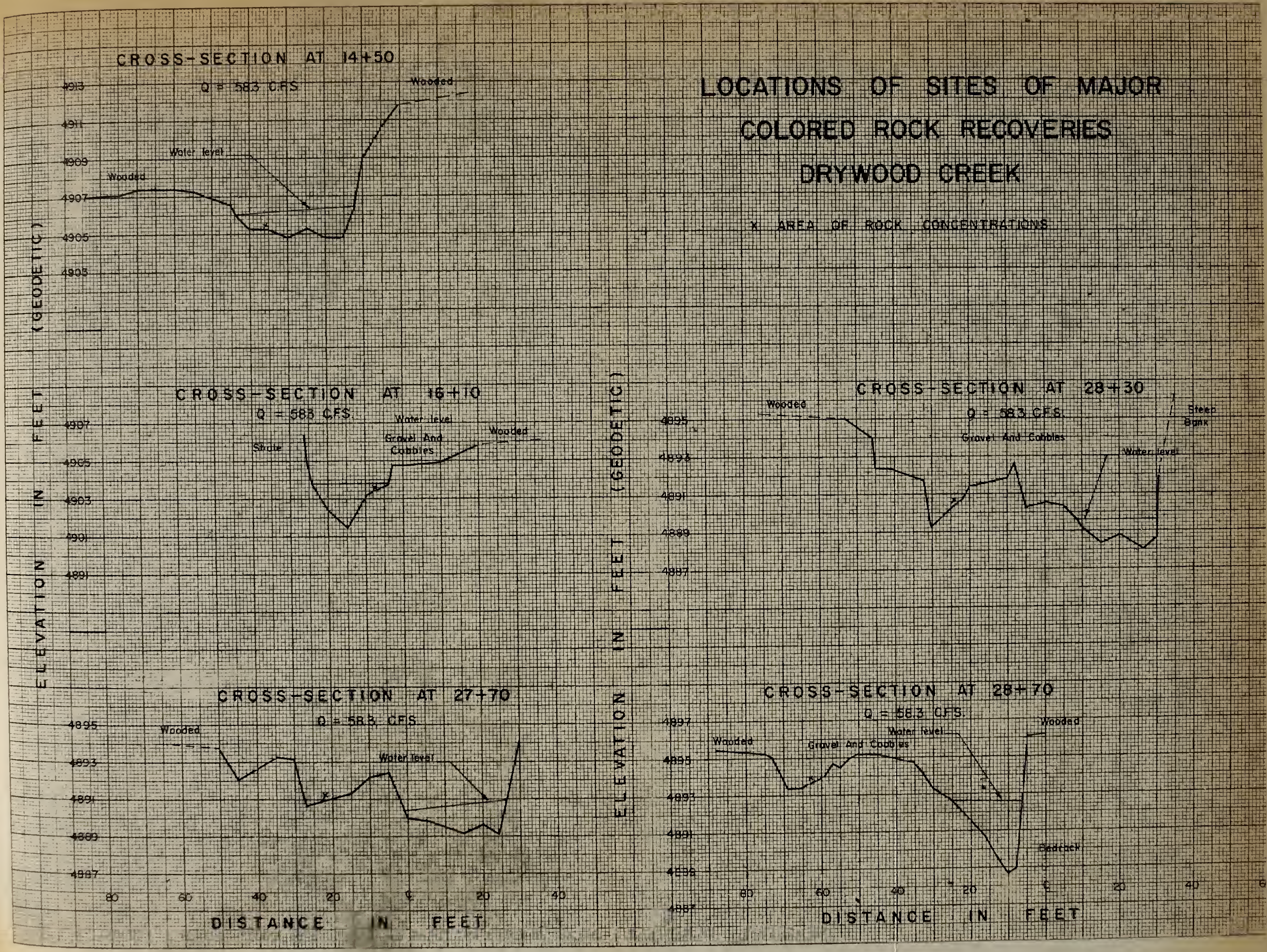


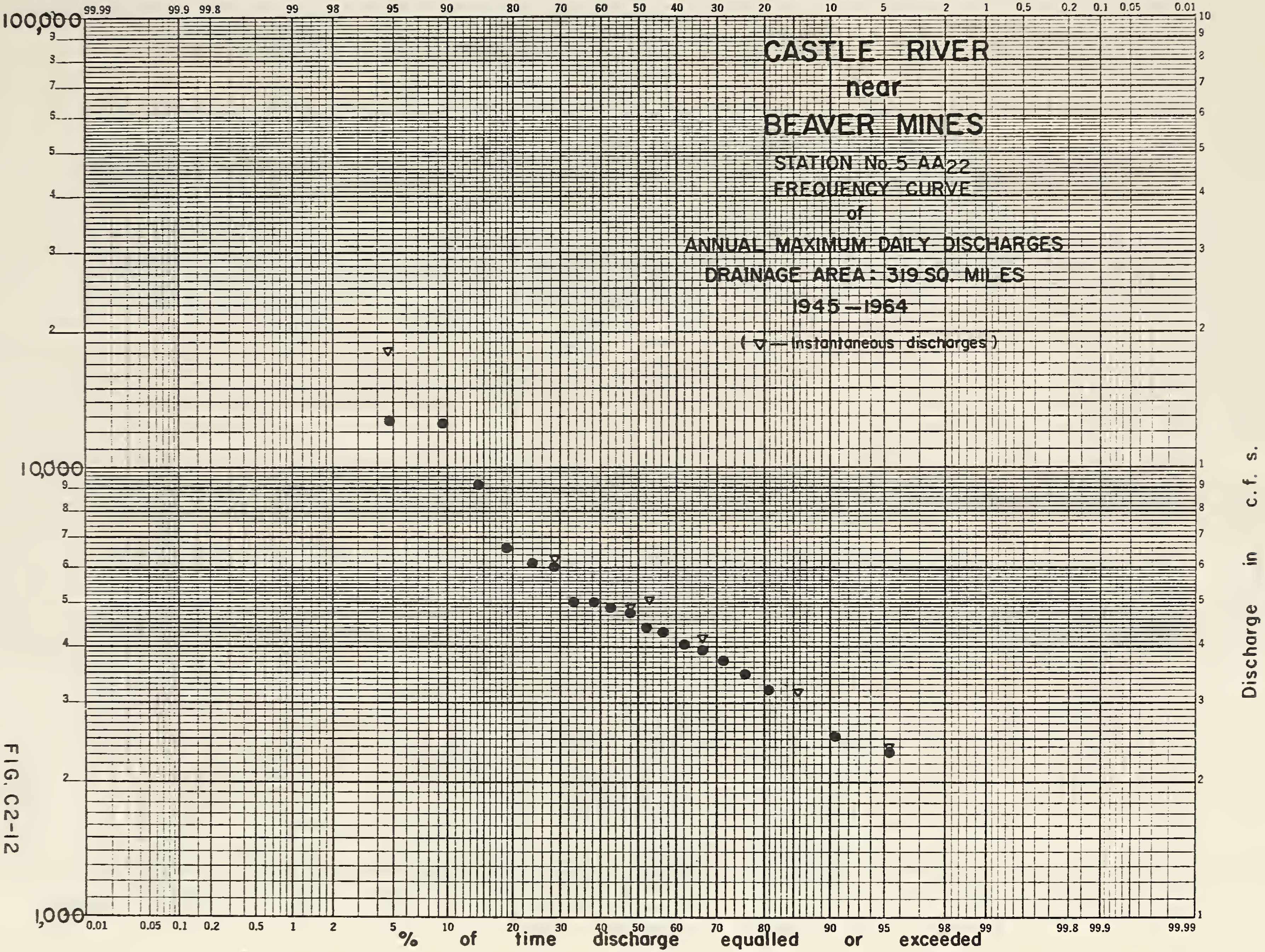
FIG. C2-10



LOCATIONS OF SITES OF MAJOR COLORED ROCK RECOVERIES DRYWOOD CREEK

X AREA OF ROCK CONCENTRATIONS

FIG. C2-11



CASTLE RIVER
near
BEAVER MINES
STATION No. 5 AA22
FREQUENCY CURVE
of
ANNUAL MAXIMUM DAILY DISCHARGES
DRAINAGE AREA : 319 SQ. MILES
1945 — 1964
(▽ — Instantaneous discharges)

FIG. C2-12

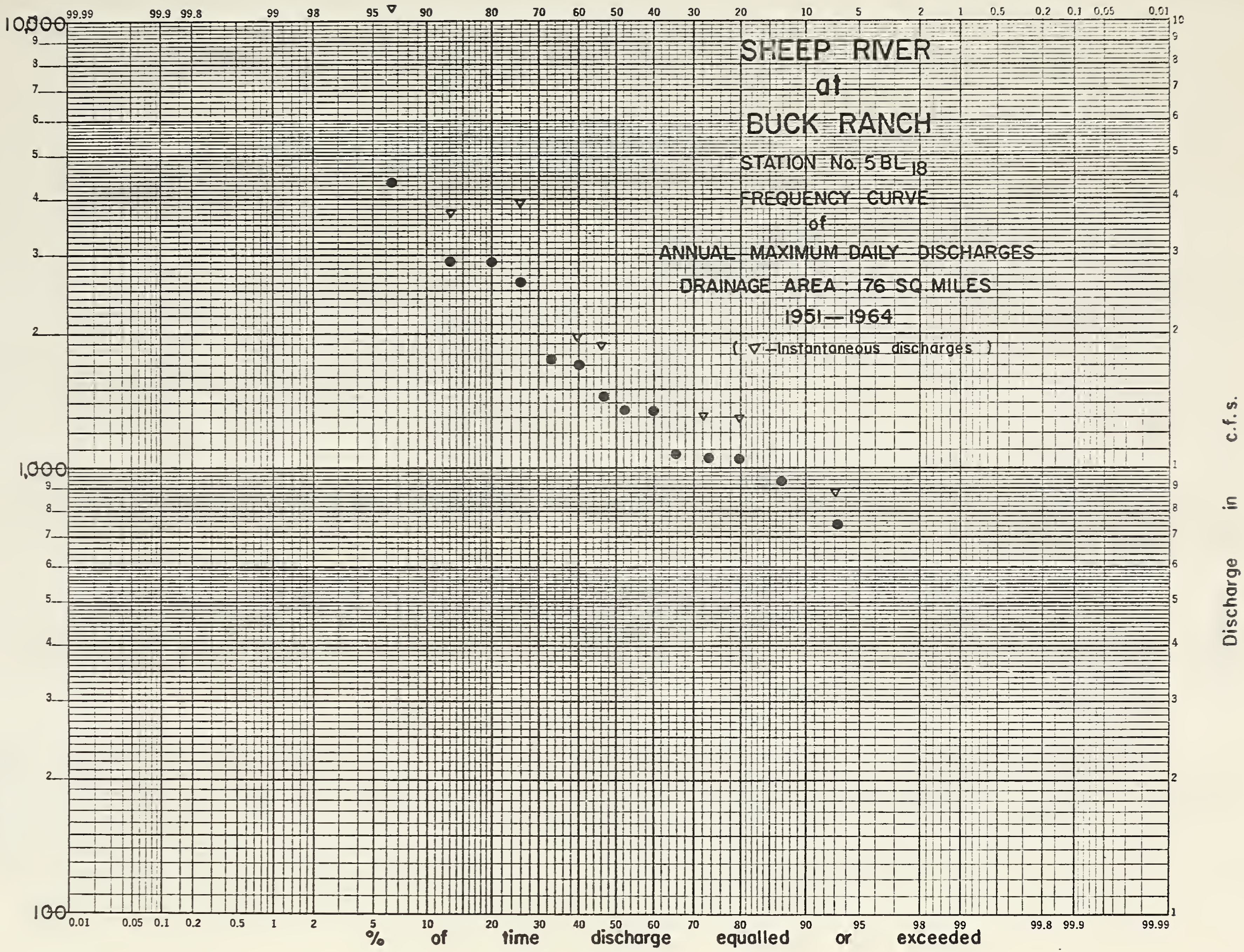

SHEEP RIVER
at
BUCK RANCH
STATION No. 5BL18
FREQUENCY CURVE
of
ANNUAL MAXIMUM DAILY DISCHARGES
DRAINAGE AREA : 176 SQ. MILES
1951—1964
(▽ –Instantaneous discharges)
% of time discharge equalled or exceeded
Discharge in c.f.s.
10,000
1,000
100
0.01
0.05
0.1
0.2
0.5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.8
99.9
99.99

FIG. C2-13

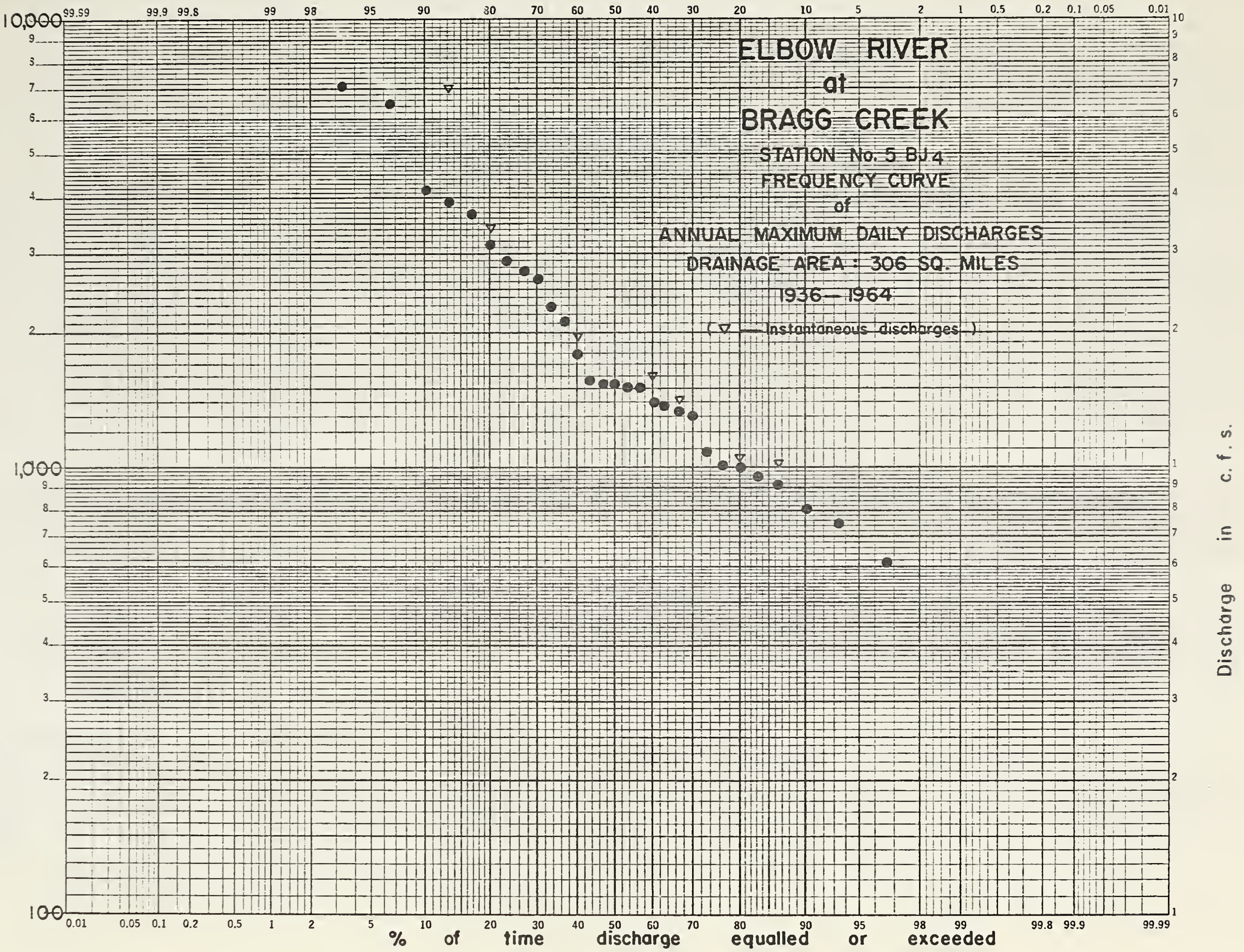

ELBOW RIVER
at
BRAGG CREEK
STATION No. 5 BJ4
FREQUENCY CURVE
of
ANNUAL MAXIMUM DAILY DISCHARGES
DRAINAGE AREA : 306 SQ. MILES
1936 — 1964
(▽ — Instantaneous discharges)
10,000
1,000
100
% of time discharge equalled or exceeded
Discharge in c. f. s.
0.01
0.05
0.1
0.2
0.5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.8
99.9
99.99

FIG. C2-14

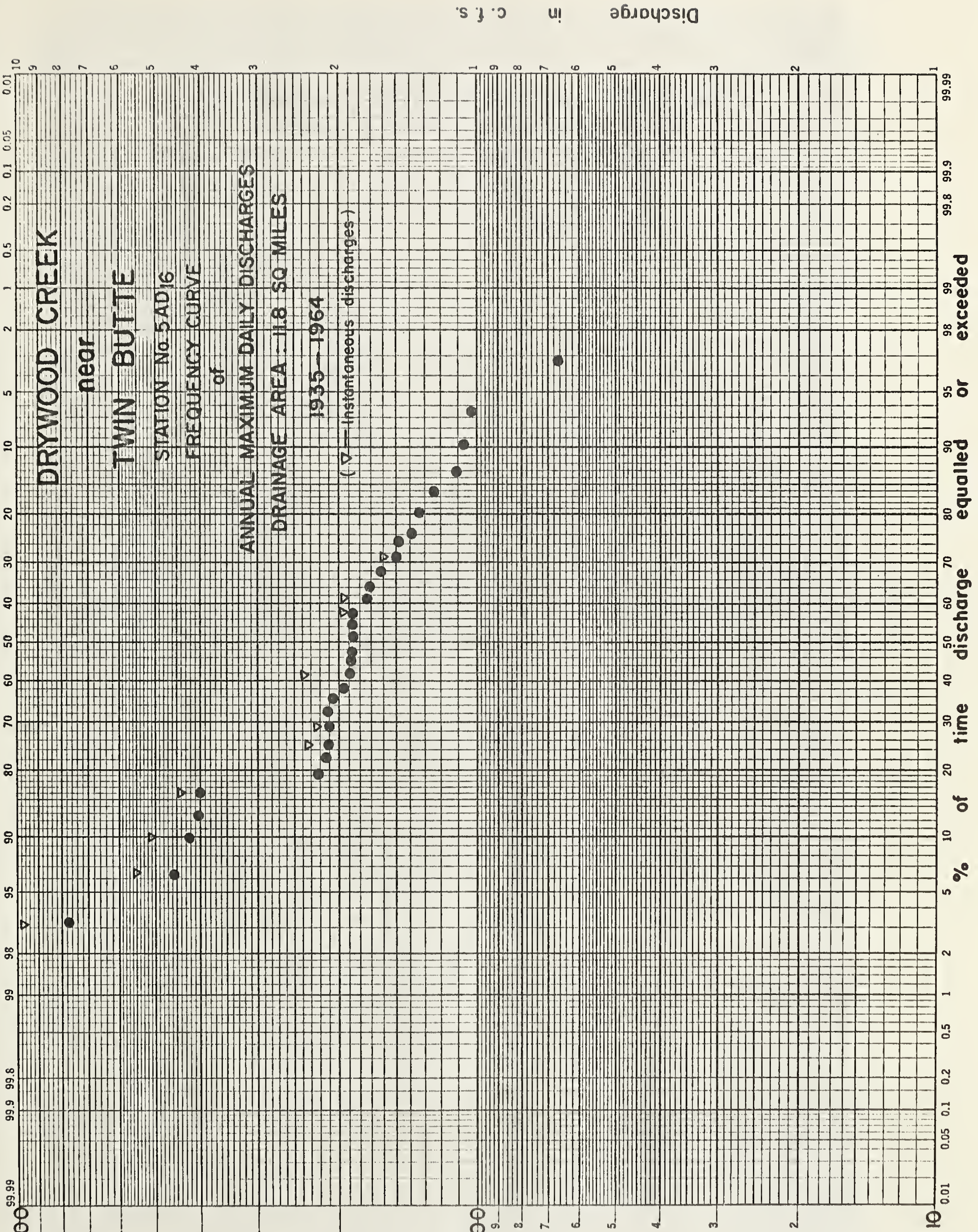

DRYWOOD CREEK
near
TWIN BUTTE
STATION No. 5AD16
FREQUENCY CURVE
of
ANNUAL MAXIMUM DAILY DISCHARGES
DRAINAGE AREA : 11.8 SQ MILES
1935 — 1964
(▽ — Instantaneous discharges)
Discharge in c. f. s.
% of time discharge equalled or exceeded
1,000
100
10
99.99
99.9
99.8
99
98
95
90
80
70
60
50
40
30
20
10
5
2
1
0.5
0.2
0.1
0.05
0.01

FIG. C2-15

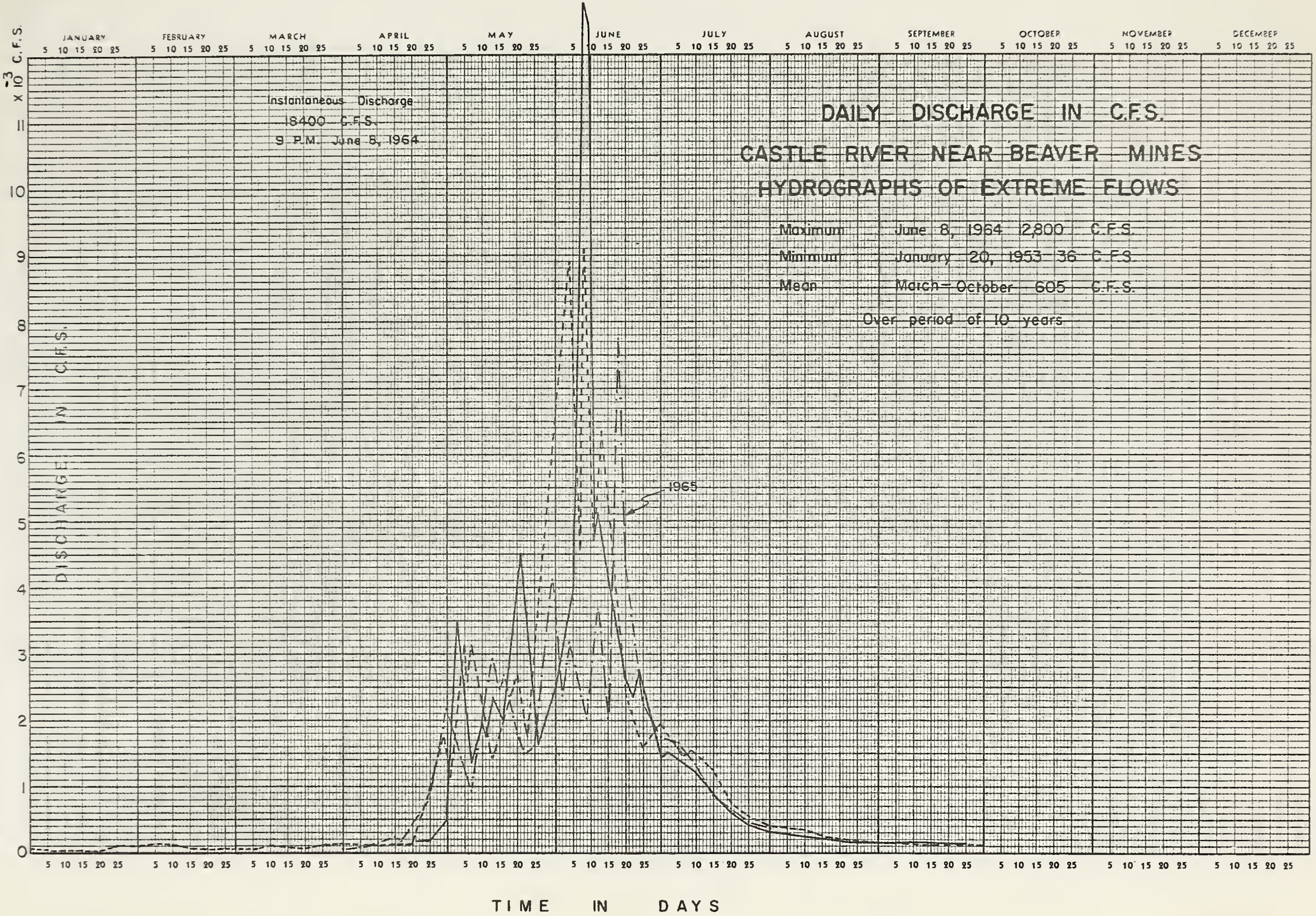

DAILY DISCHARGE IN C.F.S.
CASTLE RIVER NEAR BEAVER MINES
HYDROGRAPHS OF EXTREME FLOWS
Maximum June 8, 1964 12,800 C.F.S.
Minimum January 20, 1953 36 C.F.S.
Mean March – October 605 C.F.S.
Over period of 10 years
Instantaneous Discharge
18400 C.F.S.
9 P.M. June 8, 1964
1965
x 10^3 C.F.S.
DISCHARGE IN C.F.S.
0
1
2
3
4
5
6
7
8
9
10
11
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
5 10 15 20 25
TIME IN DAYS

FIG. C2-16

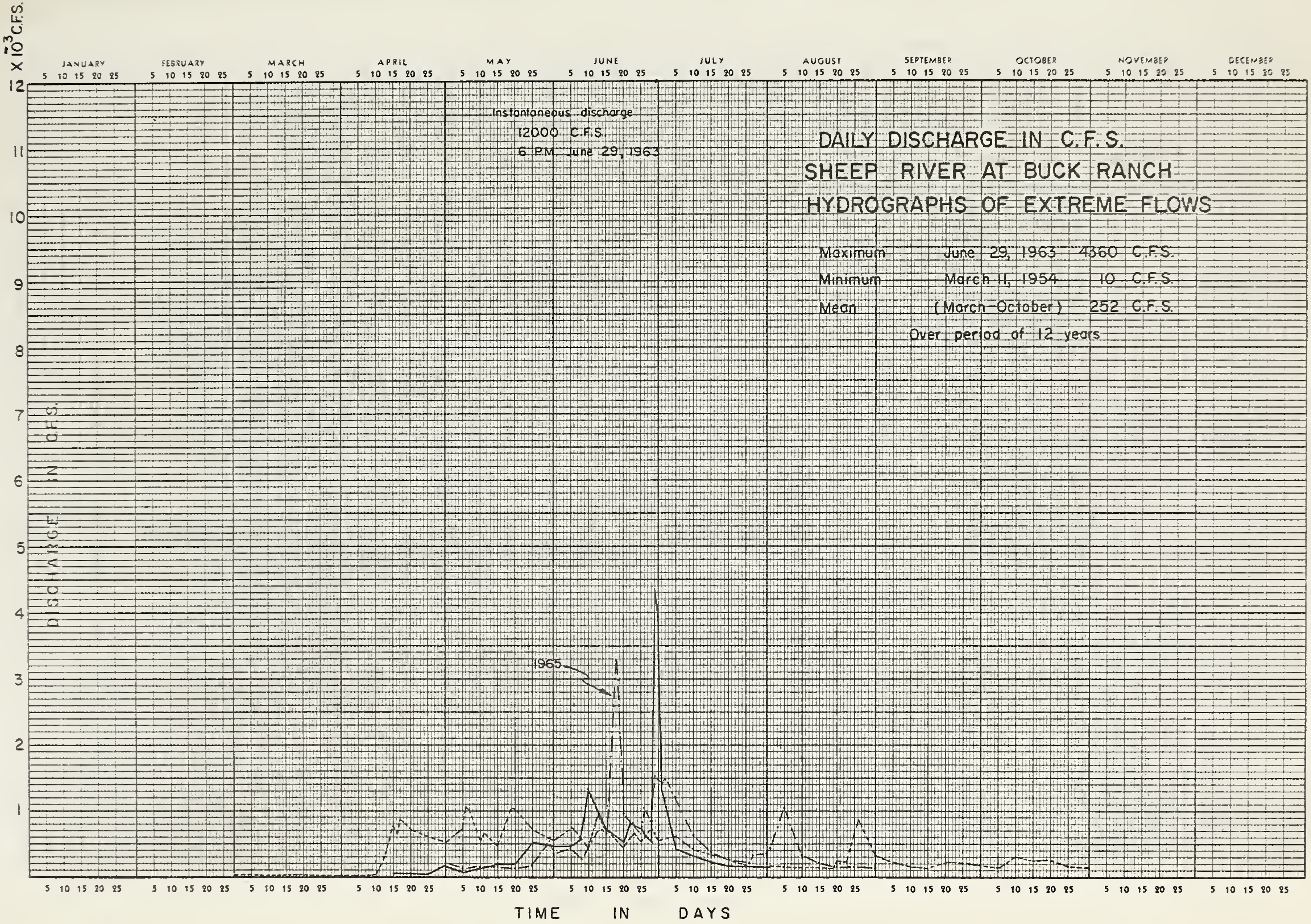

DAILY DISCHARGE IN C.F.S.
SHEEP RIVER AT BUCK RANCH
HYDROGRAPHS OF EXTREME FLOWS
Maximum June 29, 1963 4360 C.F.S.
Minimum March 11, 1954 10 C.F.S.
Mean (March-October) 252 C.F.S.
Over period of 12 years
Instantaneous discharge
12000 C.F.S.
6 P.M. June 29, 1963
1965
X 10^3 C.F.S.
DISCHARGE IN C.F.S.
12
11
10
9
8
7
6
5
4
3
2
1
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
5 10 15 20 25
TIME IN DAYS

FIG. C2-17

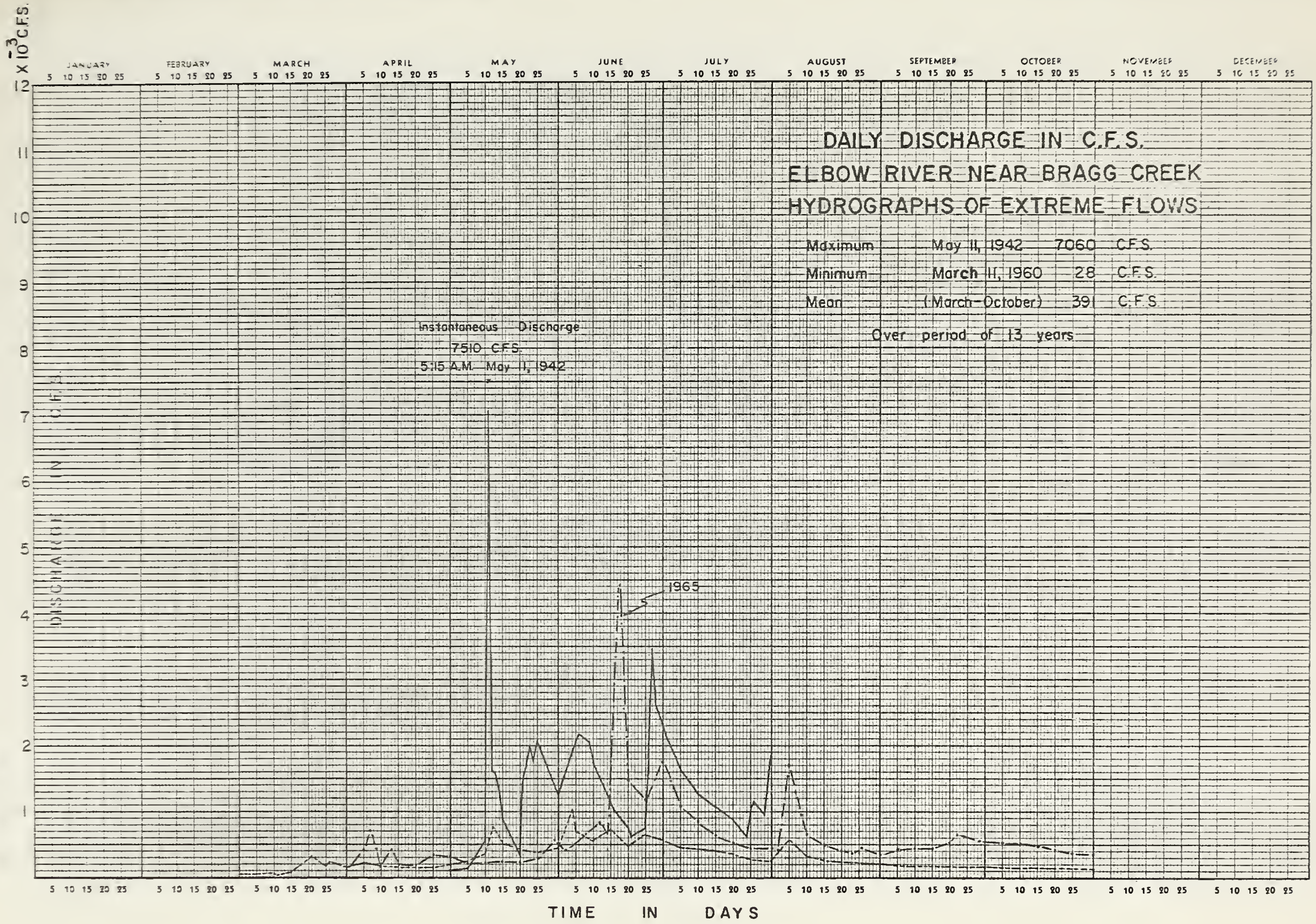

DAILY DISCHARGE IN C.F.S.
ELBOW RIVER NEAR BRAGG CREEK
HYDROGRAPHS OF EXTREME FLOWS
Maximum May 11, 1942 7060 C.F.S.
Minimum March 11, 1960 28 C.F.S.
Mean (March-October) 391 C.F.S.
Over period of 13 years
Instantaneous Discharge
7510 C.F.S.
5:15 A.M. May 11, 1942
1965
$\times 10^{-3}$ C.F.S.
DISCHARGE IN C.F.S.
12
11
10
9
8
7
6
5
4
3
2
1
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
5 10 15 20 25
TIME IN DAYS

FIG. C2-18

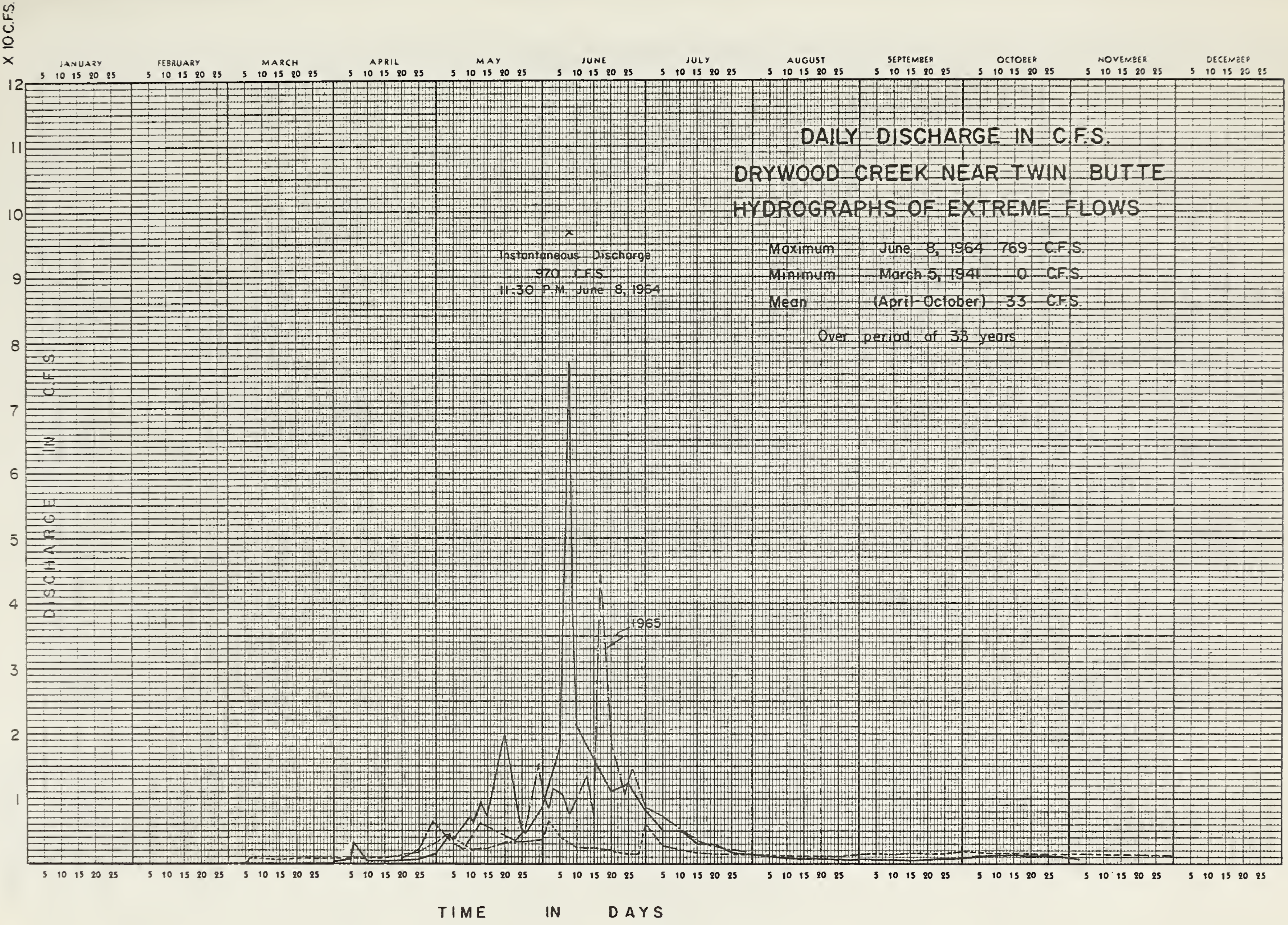

DAILY DISCHARGE IN C.F.S.
DRYWOOD CREEK NEAR TWIN BUTTE
HYDROGRAPHS OF EXTREME FLOWS
Maximum June 8, 1964 769 C.F.S.
Minimum March 5, 1941 0 C.F.S.
Mean (April-October) 33 C.F.S.
Over period of 33 years
x
Instantaneous Discharge
970 C.F.S.
11:30 P.M. June 8, 1964
1965
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
5 10 15 20 25
$\times 10^{-2}$ C.F.S.
12
11
10
9
8
7
6
5
4
3
2
1
DISCHARGE IN C.F.S.
TIME IN DAYS

FIG. C2-19

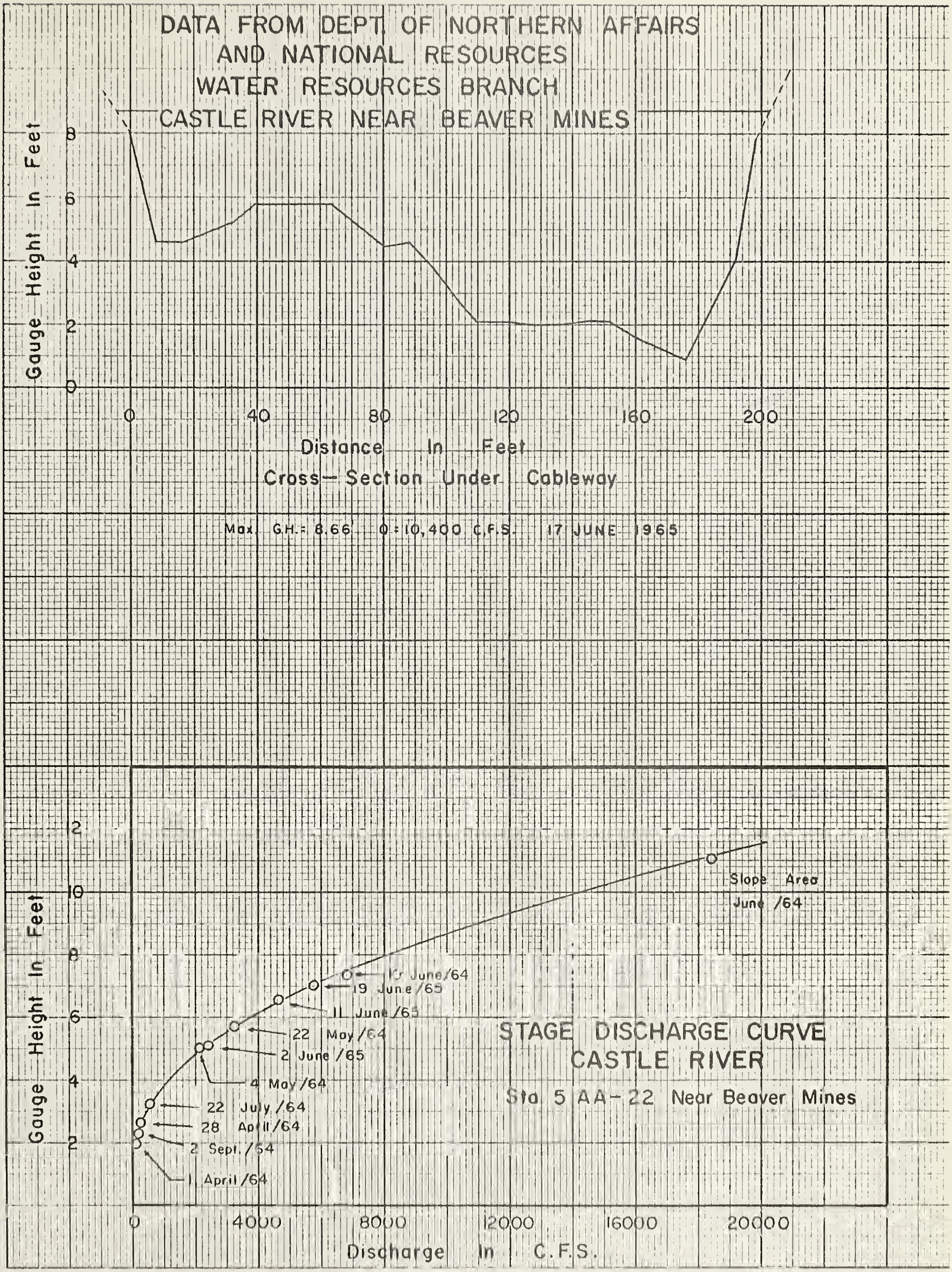

DATA FROM DEPT. OF NORTHERN AFFAIRS
AND NATIONAL RESOURCES
WATER RESOURCES BRANCH
CASTLE RIVER NEAR BEAVER MINES
Gauge Height In Feet
8
6
4
2
0
0
40
80
120
160
200
Distance In Feet
Cross — Section Under Cableway
Max. G.H.= 8.66 Q=10,400 C.F.S. 17 JUNE 1965
2
10
8
6
4
2
Gauge Height In Feet
Slope Area
June /64
16 June/64
19 June/65
11 June/65
22 May/64
2 June/65
4 May/64
22 July/64
28 April/64
2 Sept./64
1 April/64
STAGE DISCHARGE CURVE
CASTLE RIVER
Sta 5 AA-22 Near Beaver Mines
0
4000
8000
12000
16000
20000
Discharge In C.F.S.

FIG. C2-20

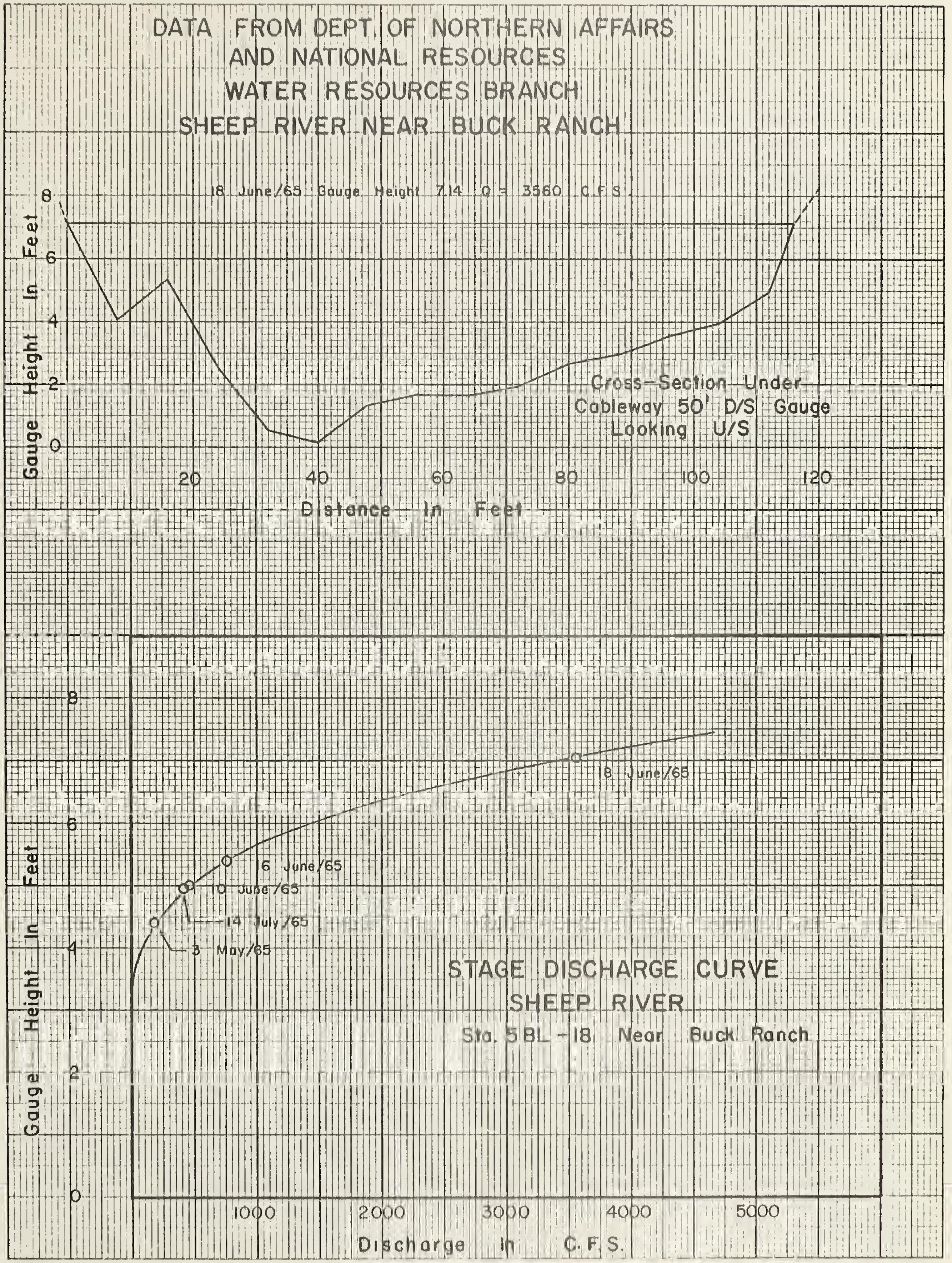

DATA FROM DEPT. OF NORTHERN AFFAIRS
AND NATIONAL RESOURCES
WATER RESOURCES BRANCH
SHEEP RIVER NEAR BUCK RANCH
18 June/65 Gauge Height 7.14 Q = 3560 C.F.S.
Gauge Height In Feet
8
6
4
2
0
Cross-Section Under
Cableway 50' D/S Gauge
Looking U/S
20
40
60
80
100
120
Distance In Feet
8
6
4
2
0
Gauge Height In Feet
18 June/65
16 June/65
10 June/65
14 July/65
3 May/65
STAGE DISCHARGE CURVE
SHEEP RIVER
Sta. 5BL-18 Near Buck Ranch
1000
2000
3000
4000
5000
Discharge in C.F.S.

FIG. C2-21

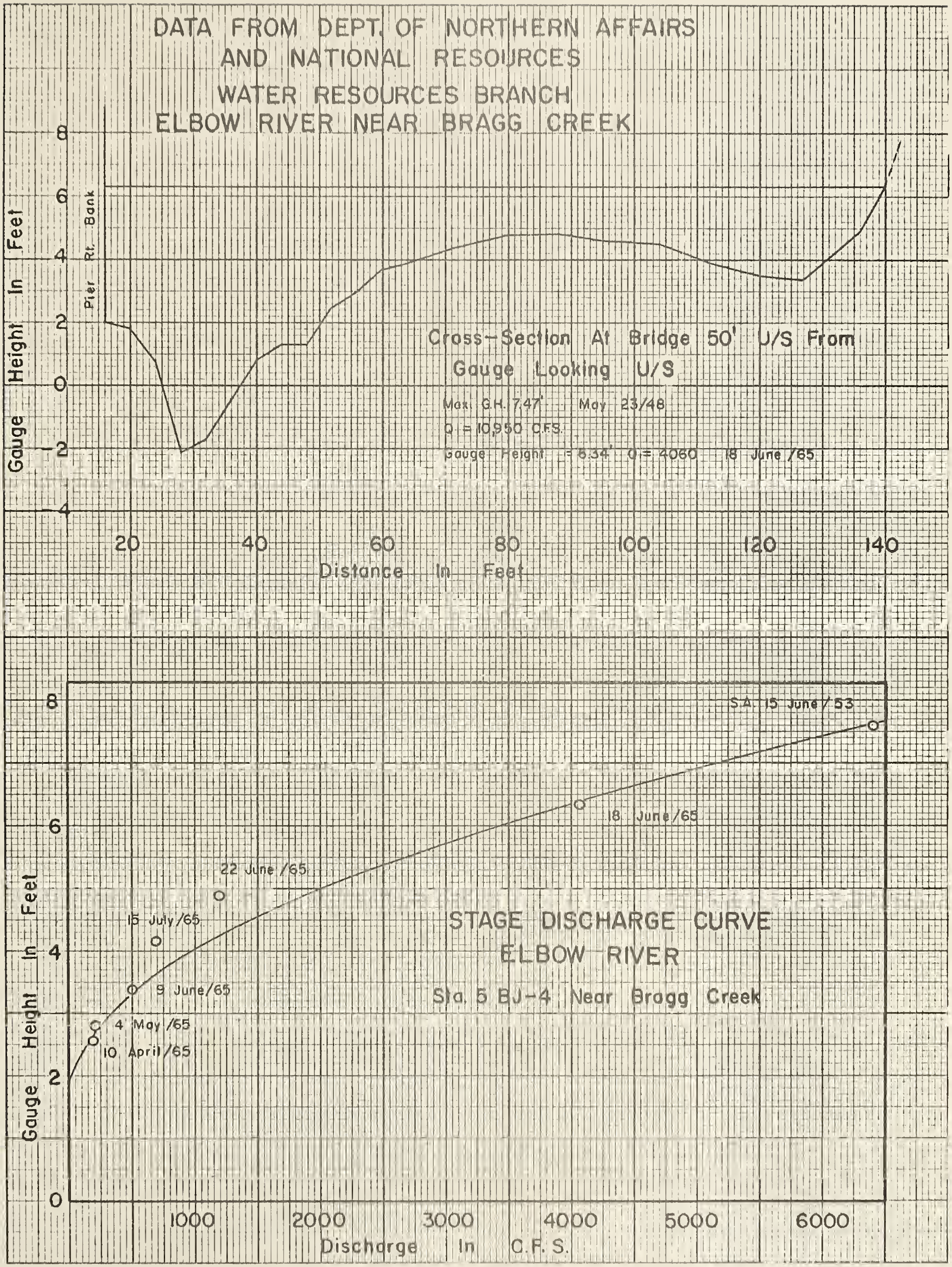
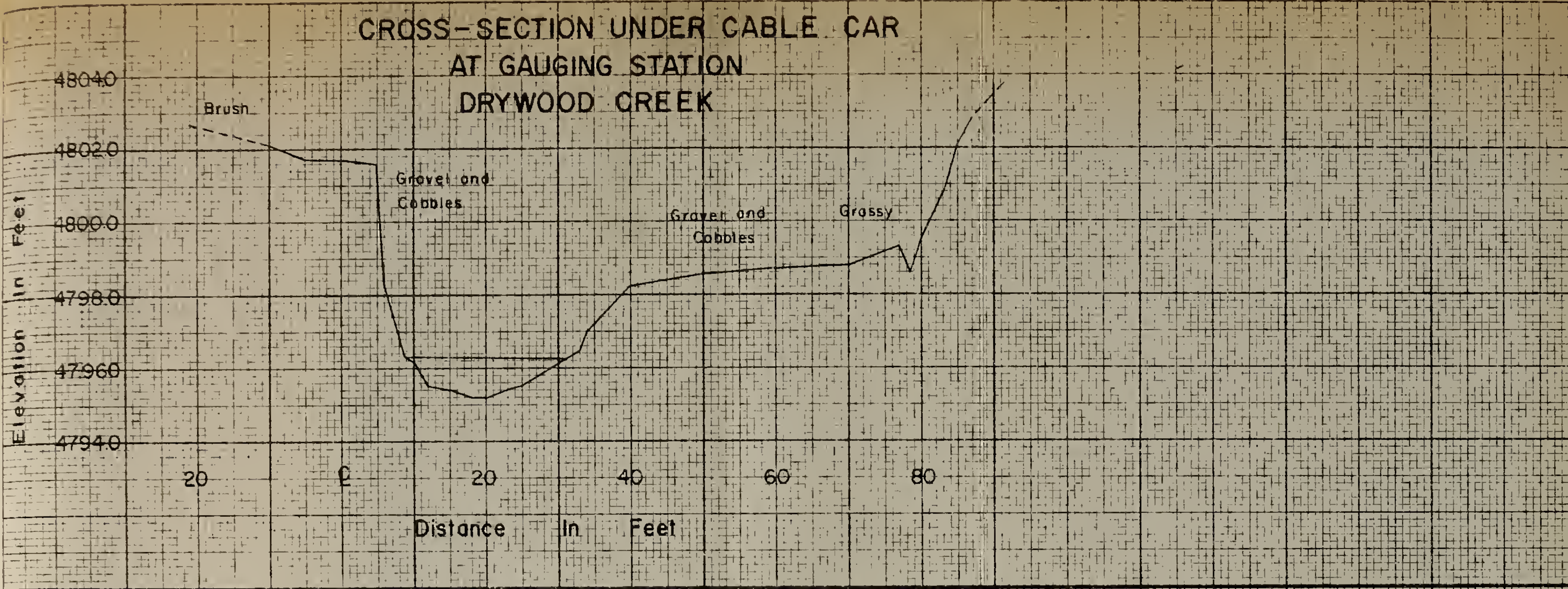
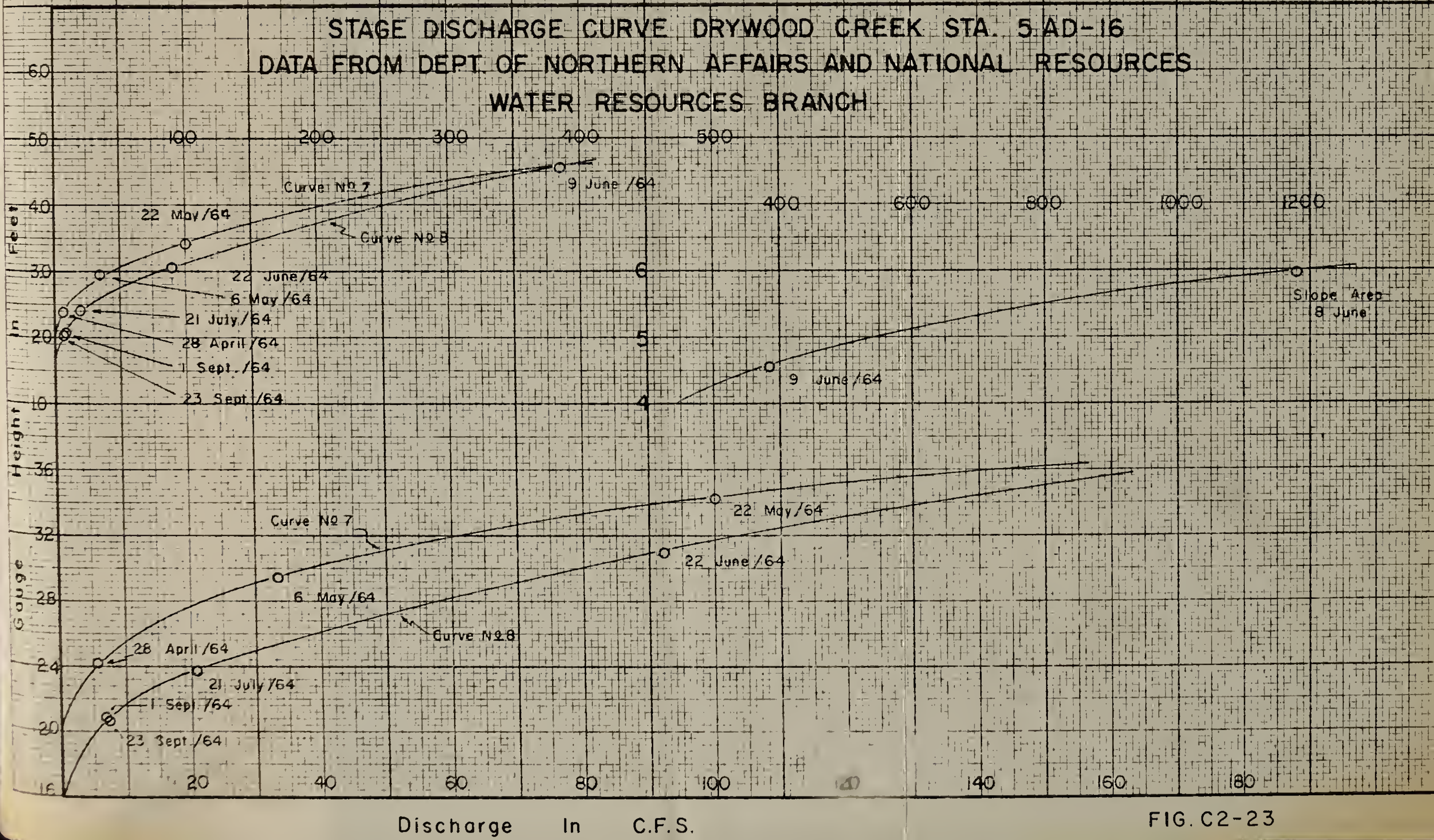

DATA FROM DEPT. OF NORTHERN AFFAIRS
AND NATIONAL RESOURCES
WATER RESOURCES BRANCH
ELBOW RIVER NEAR BRAGG CREEK
Gauge Height In Feet
8
6
4
2
0
-2
-4
Pier Rt. Bank
Cross-Section At Bridge 50' U/S From
Gauge Looking U/S
Max. G.H. 7.47' May 23/48
Q = 10,950 C.F.S.
Gauge Height = 6.34' Q = 4060 18 June/65
20
40
60
80
100
120
140
Distance In Feet
S.A. 15 June/53
18 June/65
22 June/65
15 July/65
9 June/65
4 May/65
10 April/65
STAGE DISCHARGE CURVE
ELBOW RIVER
Sta. 5 BJ-4 Near Bragg Creek
Gauge Height In Feet
8
6
4
2
0
1000
2000
3000
4000
5000
6000
Discharge In C.F.S.

FIG. C2-22

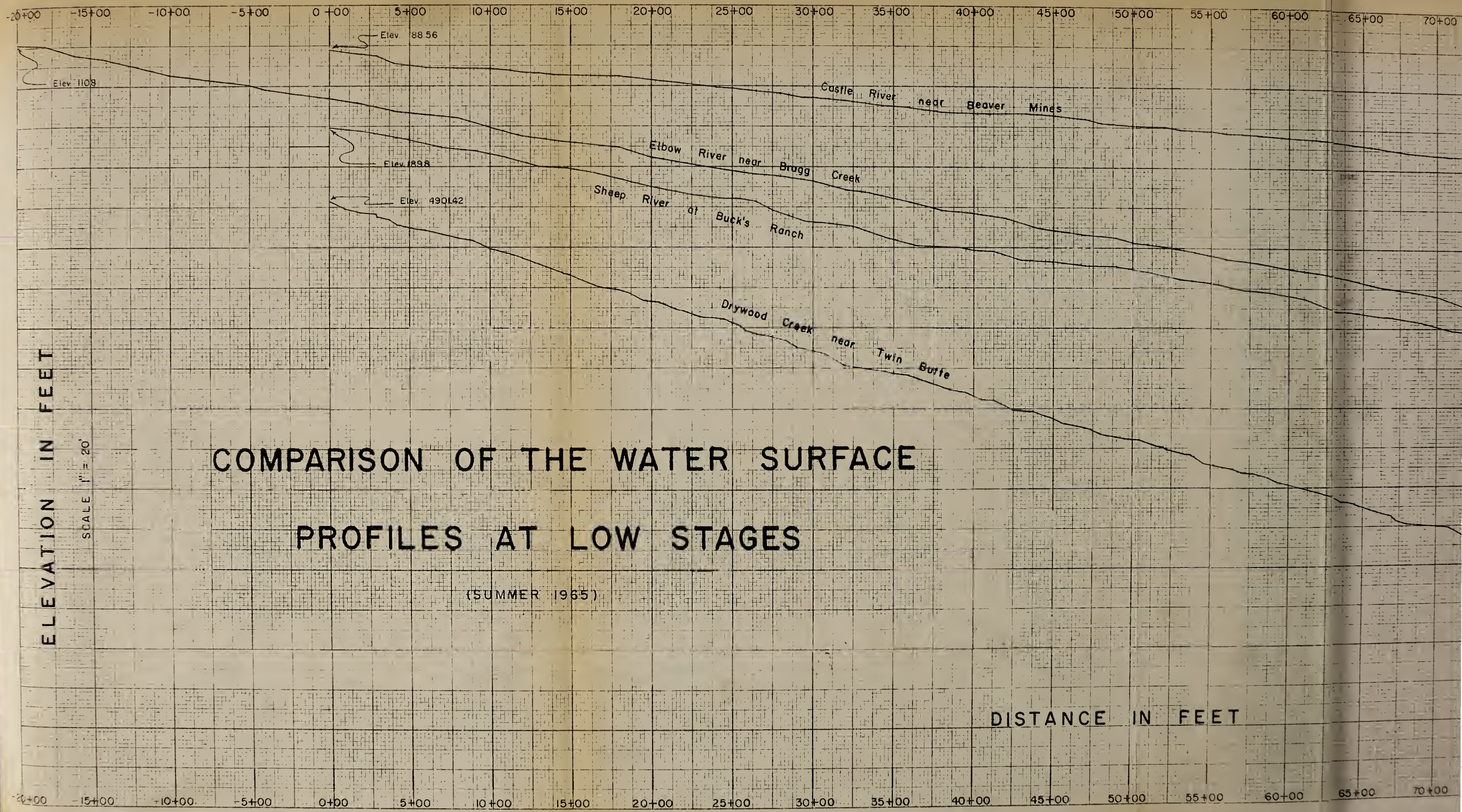


CROSS-SECTION UNDER CABLE CAR
AT GAUGING STATION
DRYWOOD CREEK



STAGE DISCHARGE CURVE DRYWOOD CREEK STA. 5 AD-16
DATA FROM DEPT OF NORTHERN AFFAIRS AND NATIONAL RESOURCES
WATER RESOURCES BRANCH

FIG. C2-23



COMPARISON OF THE WATER SURFACE PROFILES AT LOW STAGES

(SUMMER 1965)

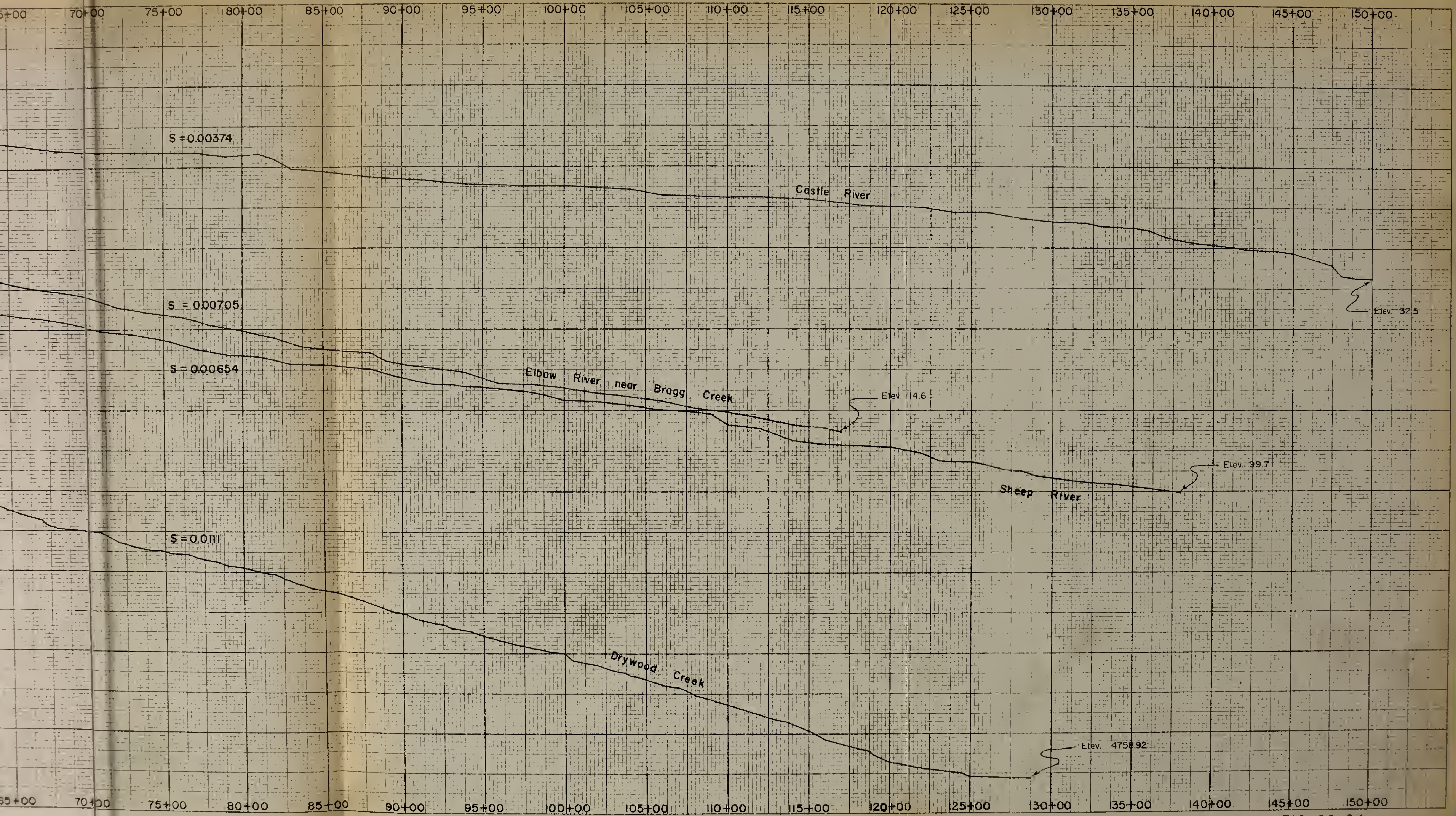

5+00
70+00
75+00
80+00
85+00
90+00
95+00
100+00
105+00
110+00
115+00
120+00
125+00
130+00
135+00
140+00
145+00
150+00
S = 0.00374
Castle River
Elev. 32.5
S = 0.00705
S = 0.00654
Elbow River near Bragg Creek
Elev 114.6
Elev. 99.7
Sheep River
S = 0.0111
Drywood Creek
Elev. 4758.92
65+00
70+00
75+00
80+00
85+00
90+00
95+00
100+00
105+00
110+00
115+00
120+00
125+00
130+00
135+00
140+00
145+00
150+00

FIG. C2-24

CASTLE RIVER CROSS-SECTIONS

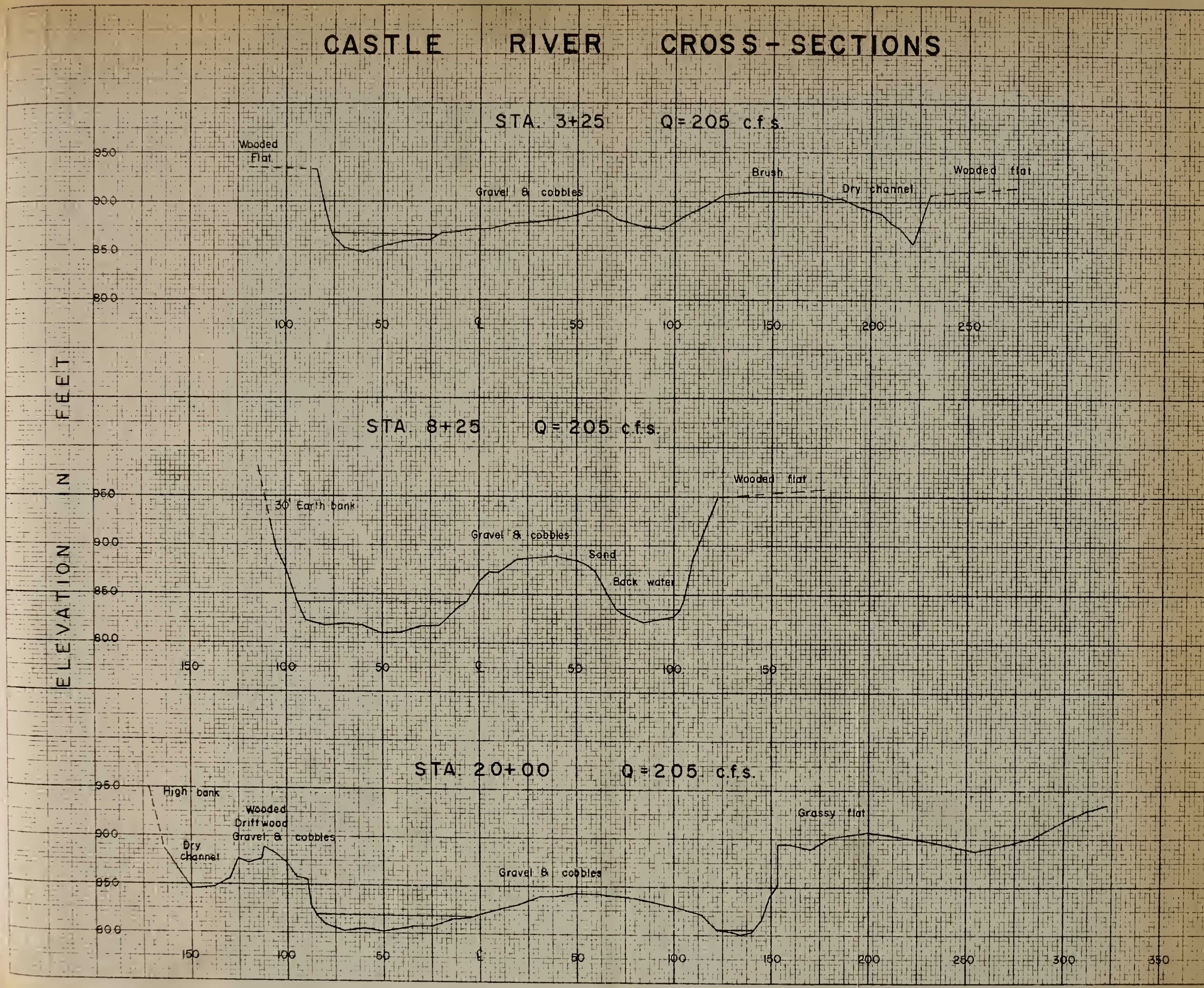


FIG. C2-25(a)

CASTLE RIVER CROSS-SECTIONS

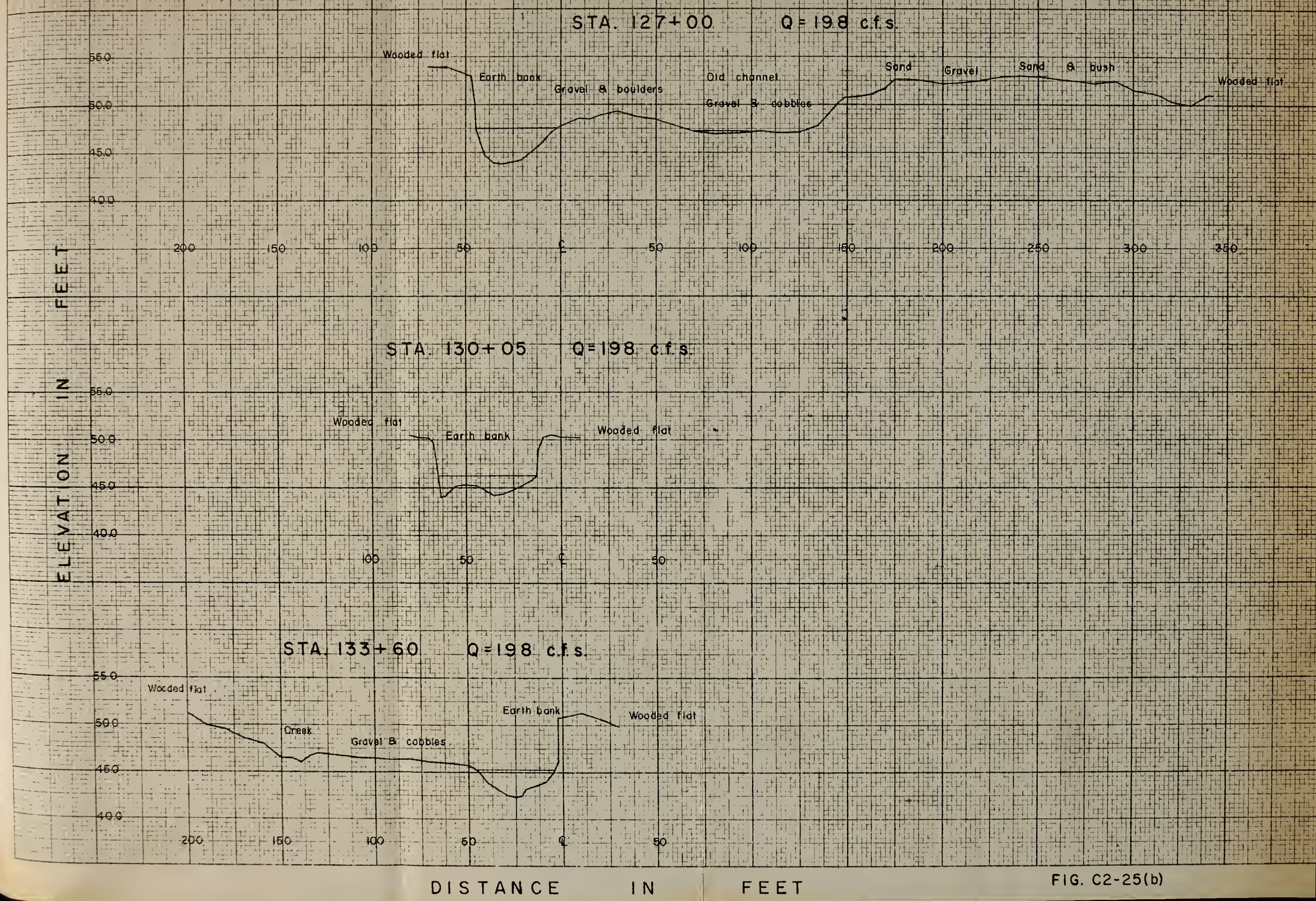


FIG. C2-25(b)

SHEEP RIVER CROSS-SECTIONS

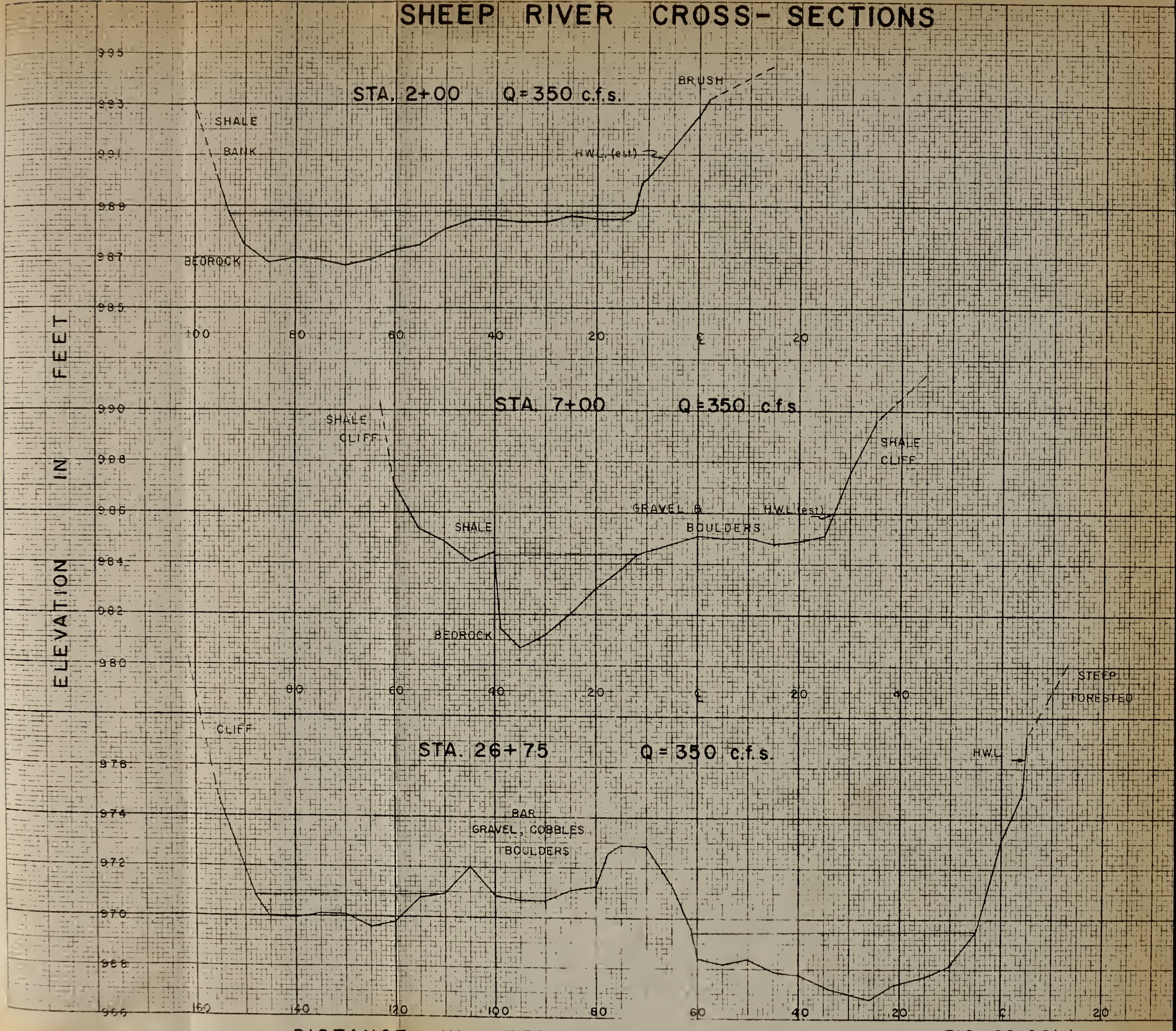


FIG. C2-26(a)

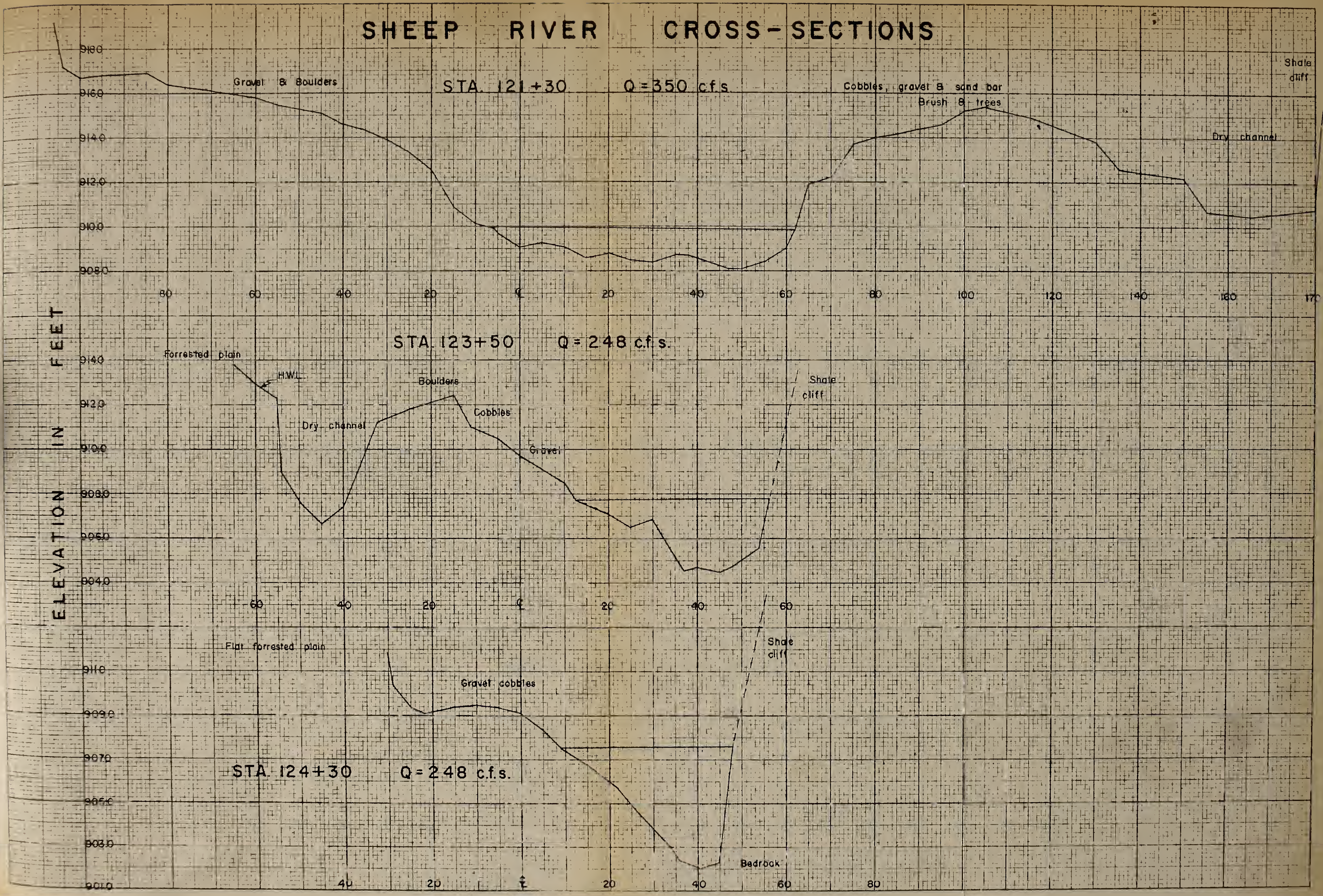
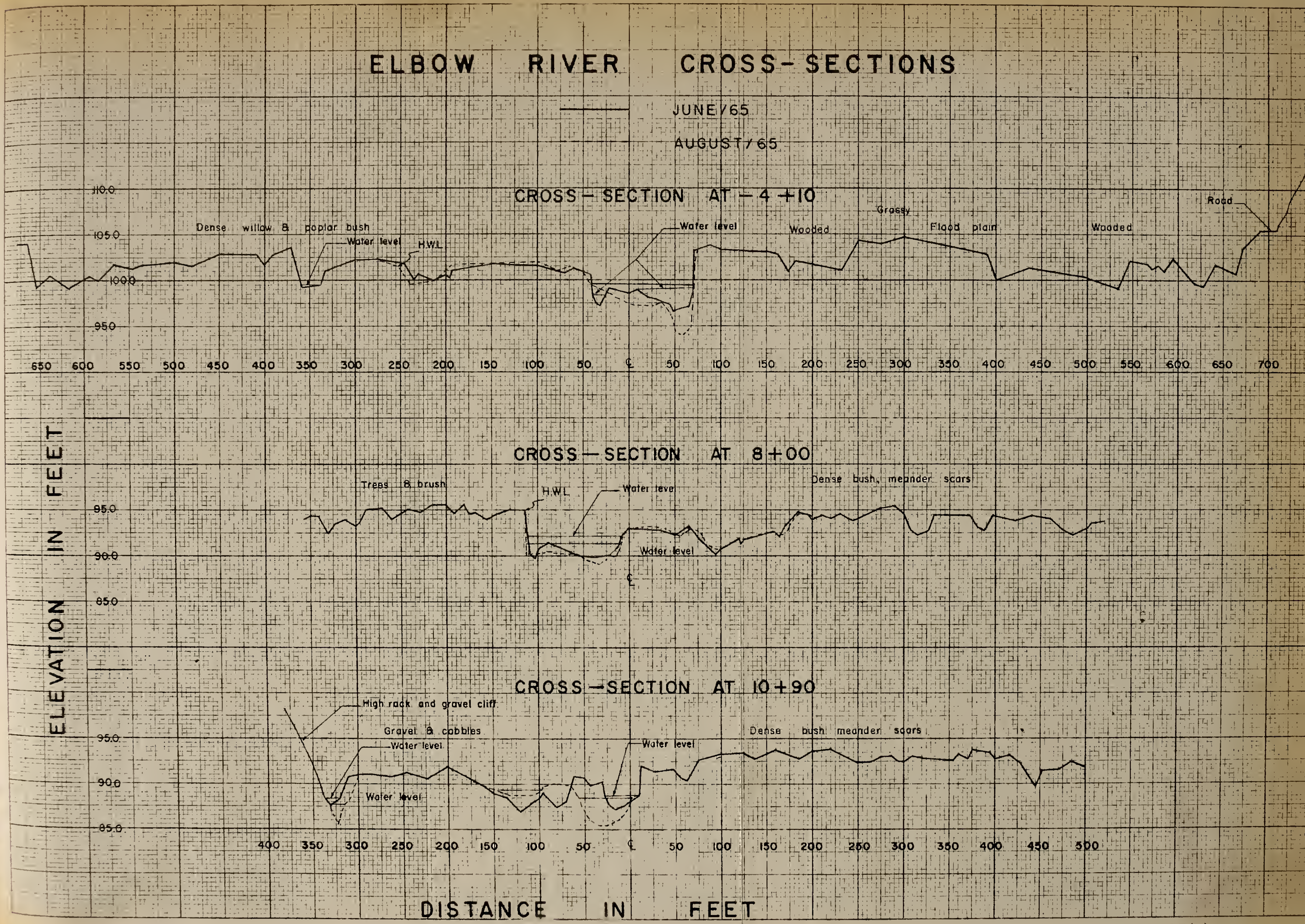

SHEEP RIVER CROSS-SECTIONS
STA. 121+30 Q=350 c.f.s.
Gravel & Boulders
Cobbles, gravel & sand bar
Brush & trees
Shale cliff
Dry channel
918.0
916.0
914.0
912.0
910.0
908.0
80
60
40
20
℄
20
40
60
80
100
120
140
160
170
STA. 123+50 Q=248 c.f.s.
Forrested plain
H.W.L.
Boulders
Cobbles
Dry channel
Gravel
Shale cliff
914.0
912.0
910.0
908.0
906.0
904.0
60
40
20
℄
20
40
60
Flat forrested plain
Gravel cobbles
Shale cliff
STA. 124+30 Q=248 c.f.s.
Bedrock
911.0
909.0
907.0
905.0
903.0
901.0
40
20
℄
20
40
60
80
ELEVATION IN FEET
DISTANCE IN FEET

FIG. C2-26(b)



ELBOW RIVER CROSS-SECTIONS

FIG. C2-27(a)

ELBOW RIVER CROSS-SECTIONS

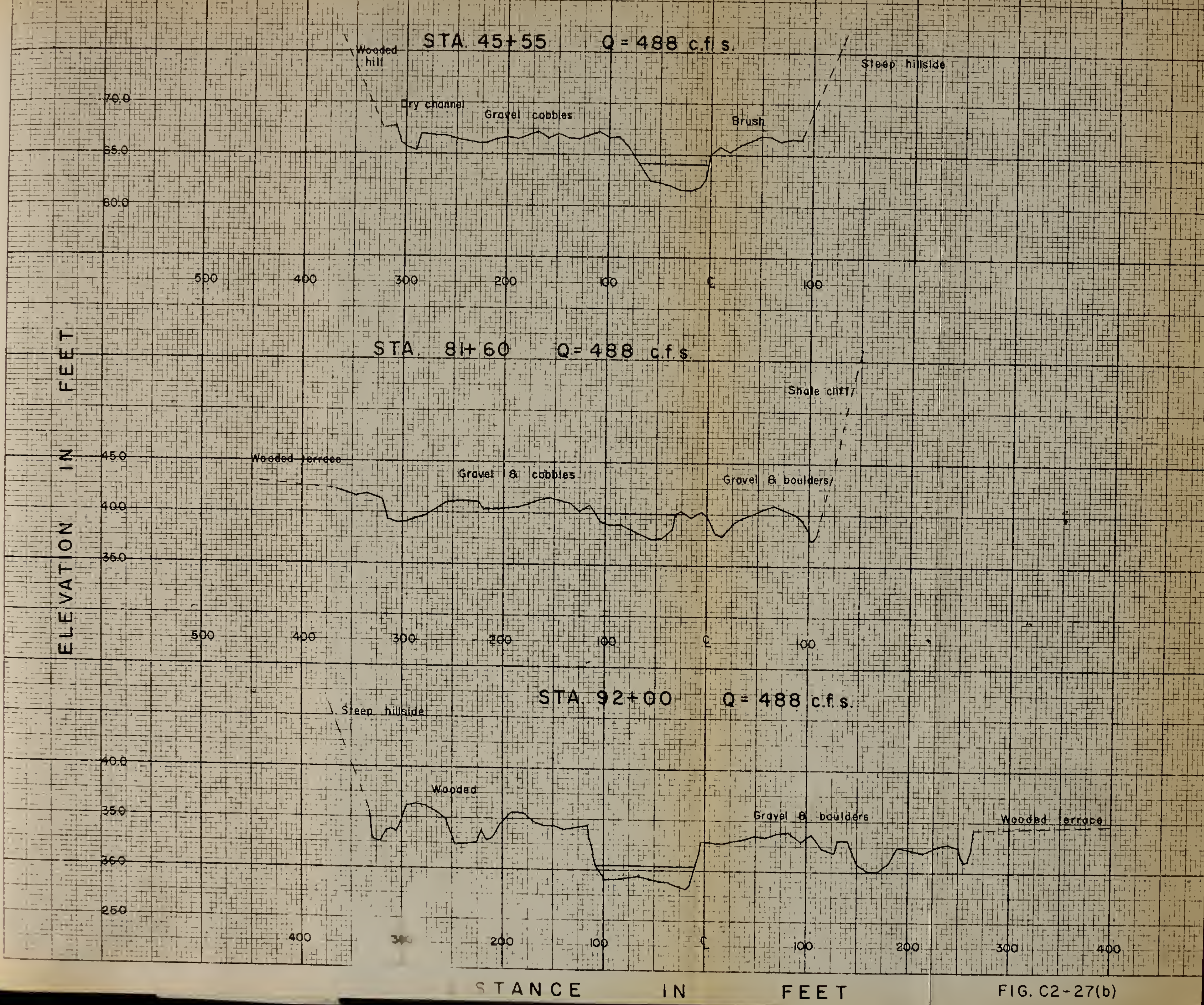


FIG. C2-27(b)

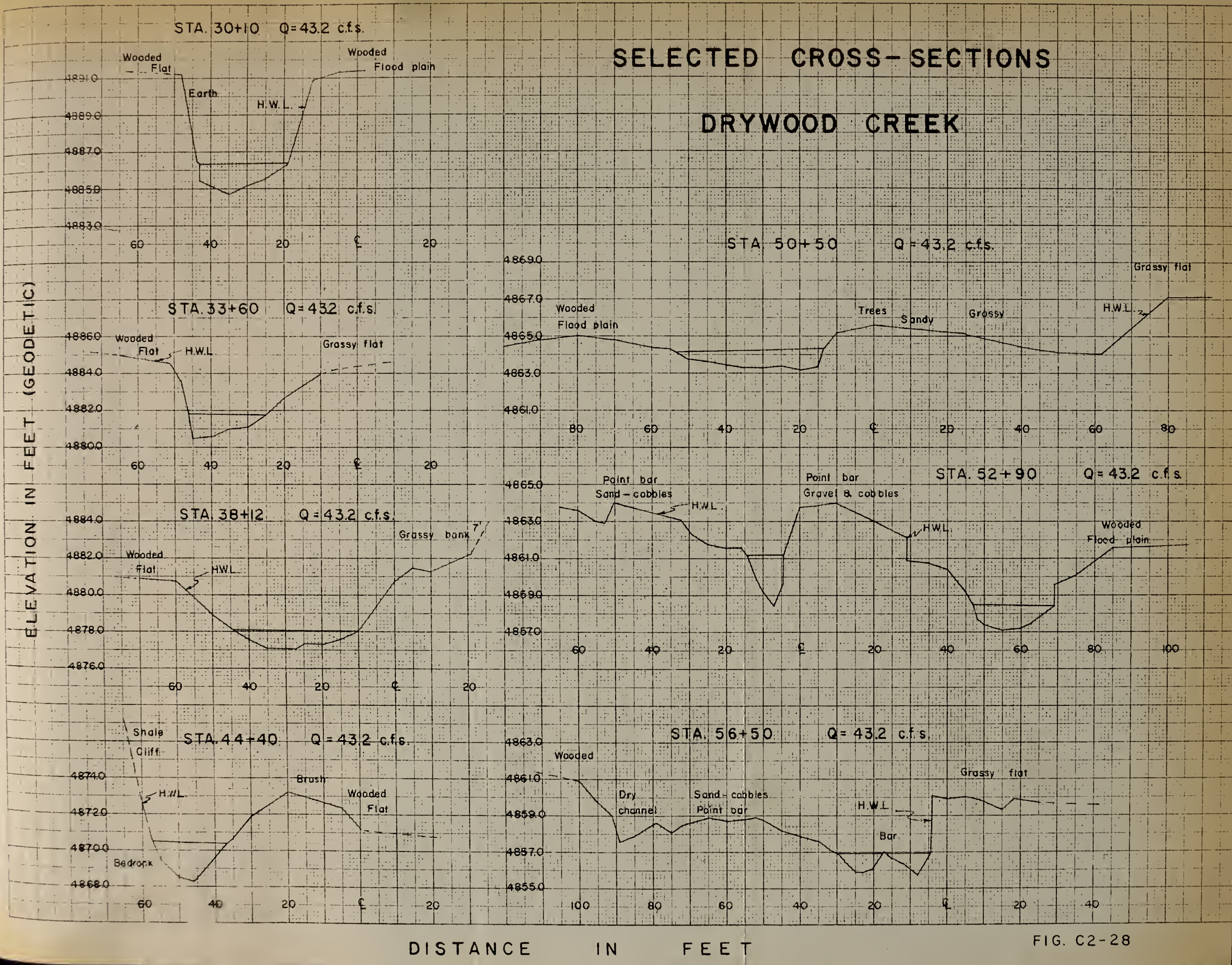
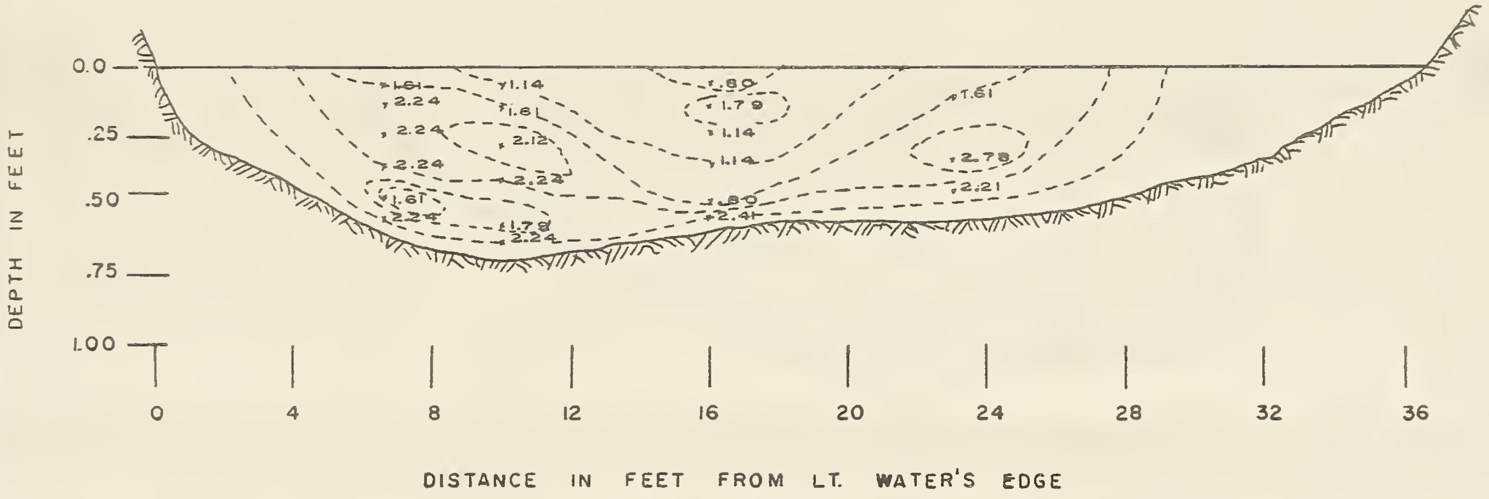

SELECTED CROSS-SECTIONS
DRYWOOD CREEK
ELEVATION IN FEET (GEODETIC)
DISTANCE IN FEET
STA. 30+10 Q=43.2 c.f.s.
Wooded Flat
Earth
H.W.L.
Wooded Flood plain
4891.0
4889.0
4887.0
4885.0
4883.0
60
40
20
℄
20
STA. 33+60 Q=43.2 c.f.s.
Wooded Flat
H.W.L.
Grassy flat
4886.0
4884.0
4882.0
4880.0
60
40
20
℄
20
STA. 38+12 Q=43.2 c.f.s.
Wooded Flat
HWL
Grassy bank
4884.0
4882.0
4880.0
4878.0
4876.0
60
40
20
℄
20
STA. 44+40 Q=43.2 c.f.s.
Shale Cliff
H.W.L.
Brush
Wooded Flat
Bedrock
4874.0
4872.0
4870.0
4868.0
60
40
20
℄
20
STA. 50+50 Q=43.2 c.f.s.
Wooded Flood plain
Trees
Sandy
Grassy
H.W.L.
Grassy flat
4869.0
4867.0
4865.0
4863.0
4861.0
80
60
40
20
℄
20
40
60
80
STA. 52+90 Q=43.2 c.f.s.
Point bar Sand – cobbles
H.W.L.
Point bar Gravel & cobbles
HWL
Wooded Flood plain
4865.0
4863.0
4861.0
4859.0
4857.0
60
40
20
℄
20
40
60
80
100
STA. 56+50 Q=43.2 c.f.s.
Wooded
Dry channel
Sand - cobbles Point bar
H.W.L.
Bar
Grassy flat
4863.0
4861.0
4859.0
4857.0
4855.0
100
80
60
40
20
℄
20
40

FIG. C2-28

VELOCITY DISTRIBUTION

STA. 57+60
JULY 14, 1965

DISCHARGE OF 36 c.f.s.



DRYWOOD CREEK

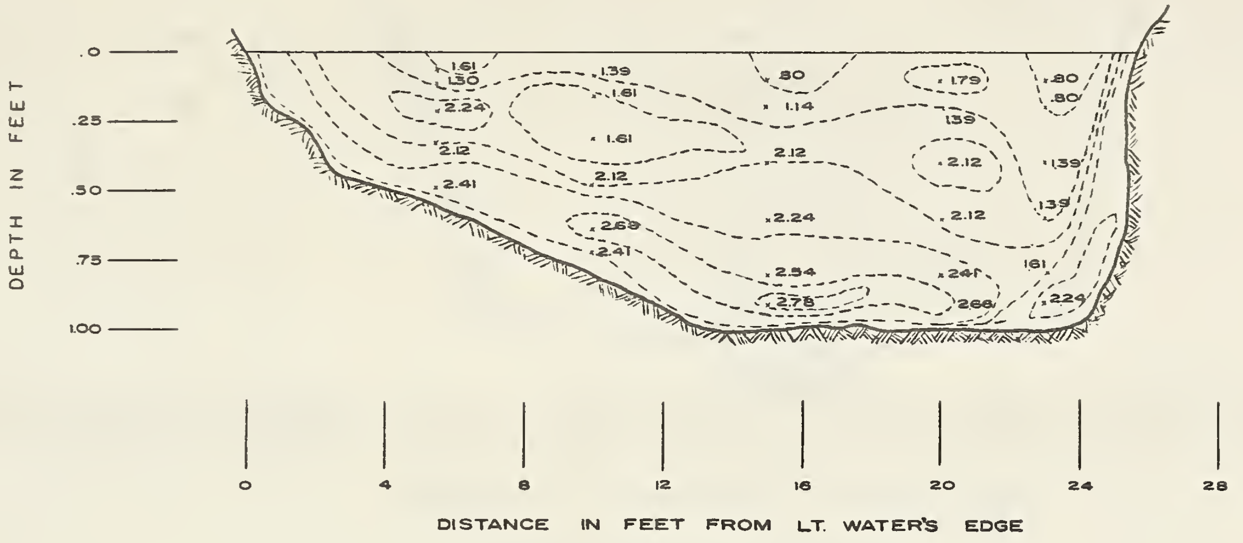
FIG. C2-29

VELOCITY DISTRIBUTION

STA. 72+75

JULY 14, 1965

DISCHARGE OF 36 c.f.s.



DRYWOOD CREEK

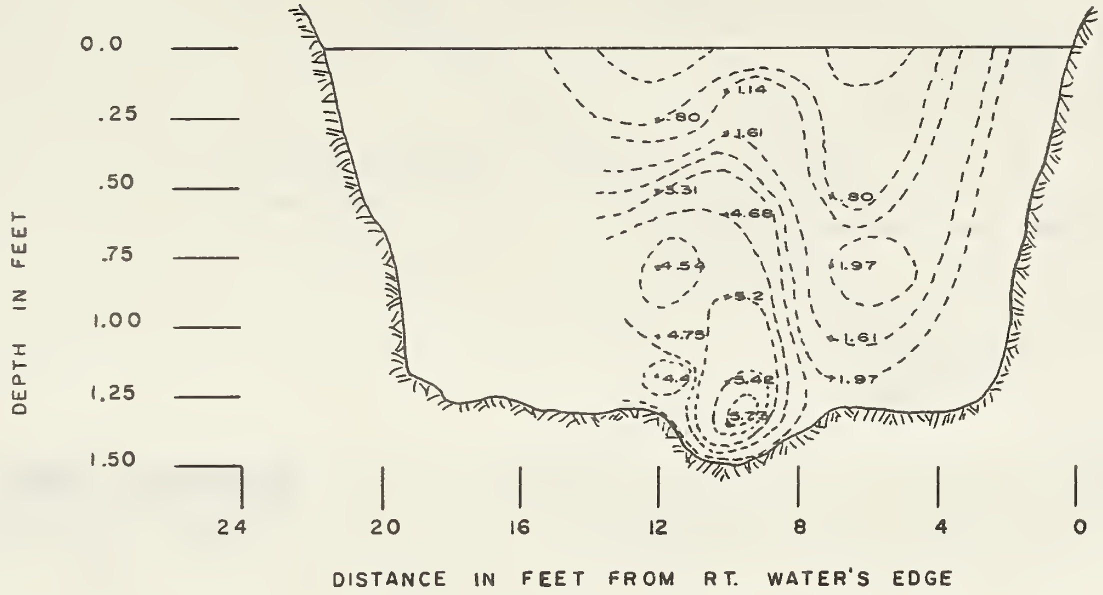
FIG. C2-30

VELOCITY DISTRIBUTION

STA. 110 + 25

JULY 14, 1965

DISCHARGE OF 36 c.f.s.



DRYWOOD CREEK

FIG. C2-31

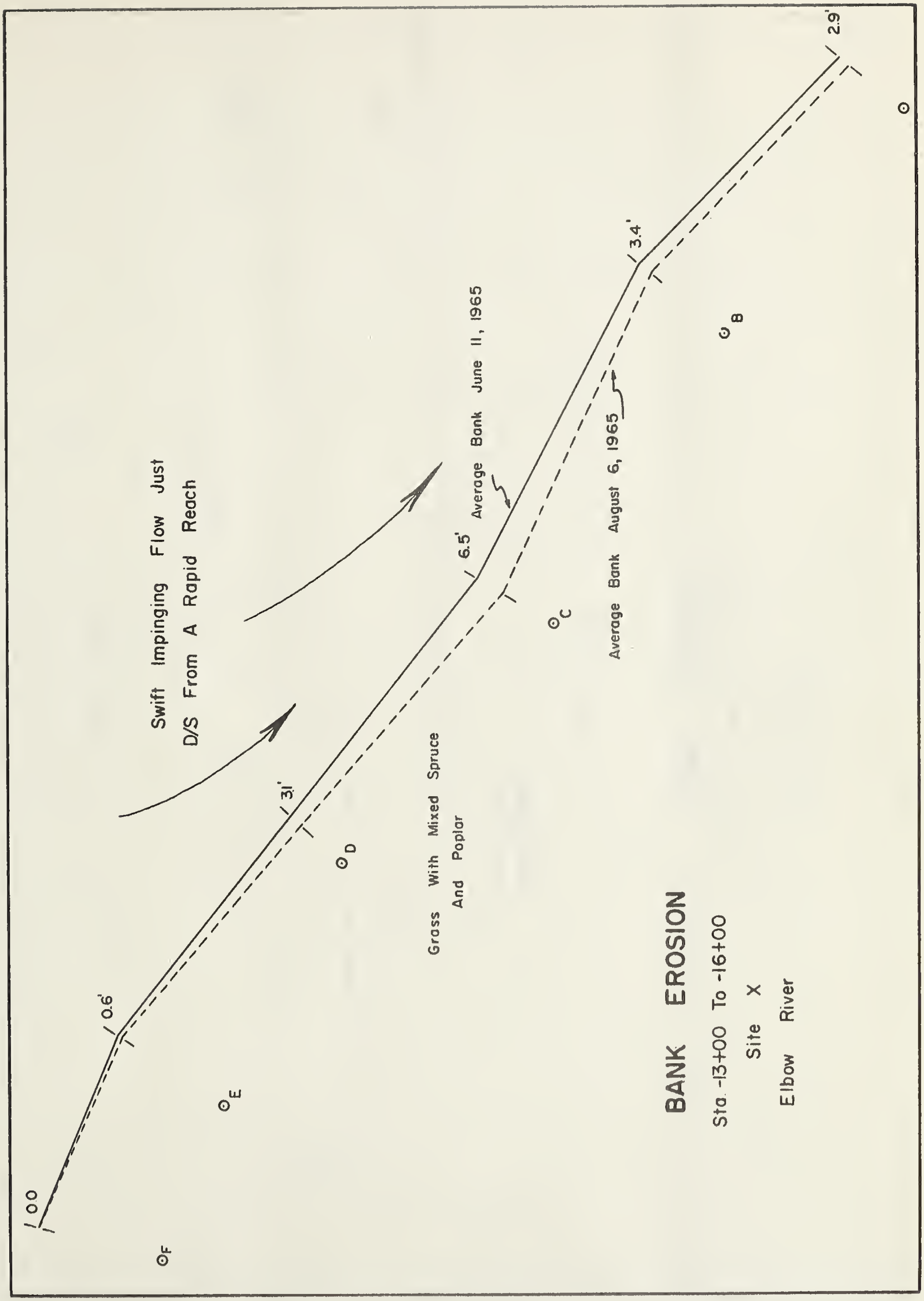
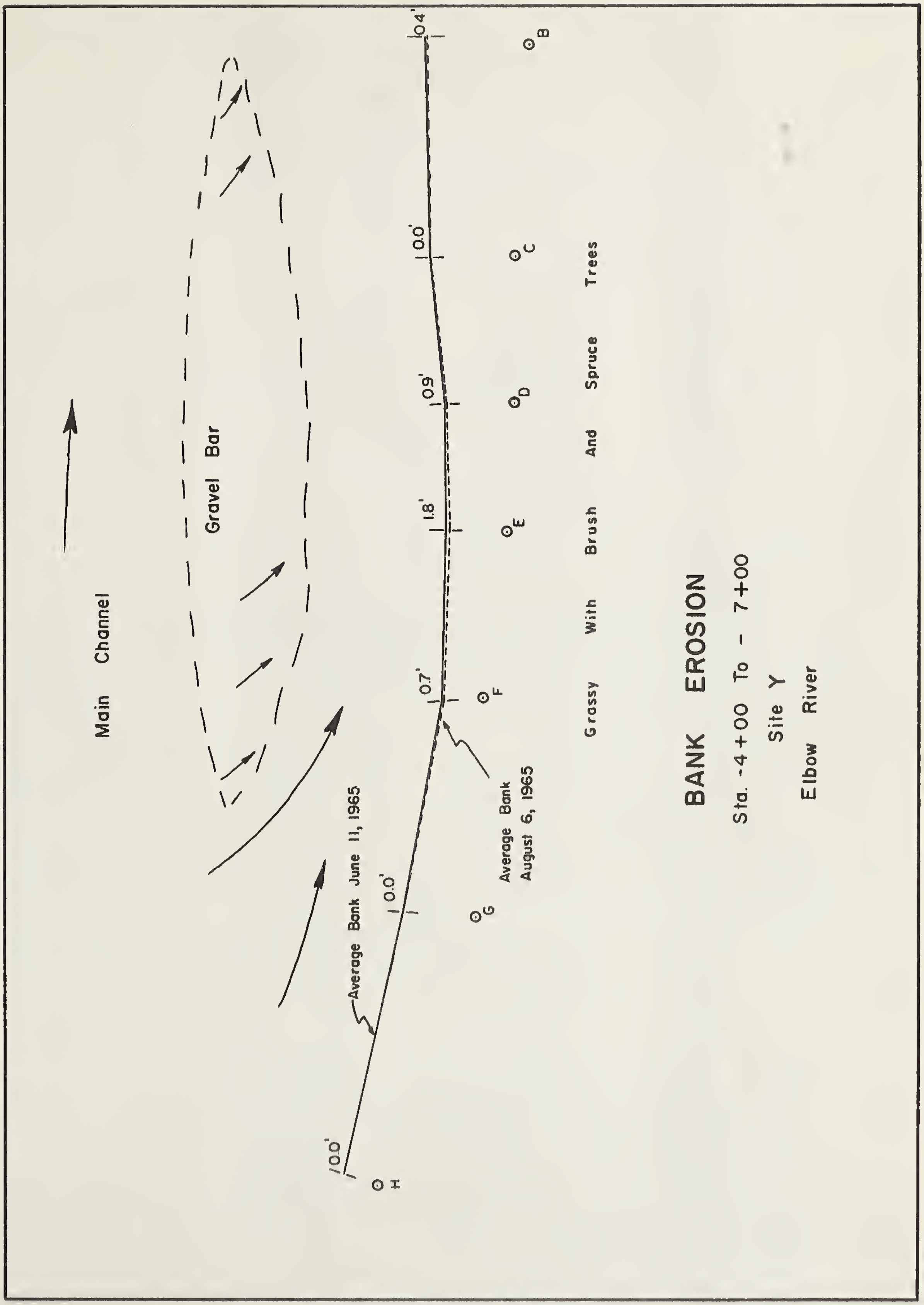

BANK EROSION
Sta. -13+00 To -16+00
Site X
Elbow River
Swift Impinging Flow Just D/S From A Rapid Reach
Average Bank June 11, 1965
Average Bank August 6, 1965
Grass With Mixed Spruce And Poplar
1.00
0.6'
3.1'
6.5'
3.4'
2.9'
B
C
D
E
F

FIG. C2-32



BANK EROSION
Sta. -4+00 To - 7+00
Site Y
Elbow River

Main Channel
Gravel Bar
Grassy With Brush And Spruce Trees
Average Bank June 11, 1965
Average Bank August 6, 1965
10.0'
0.0'
0.7'
1.8'
0.9'
0.0'
0.4'
H
G
F
E
D
C
B

FIG. C2-33

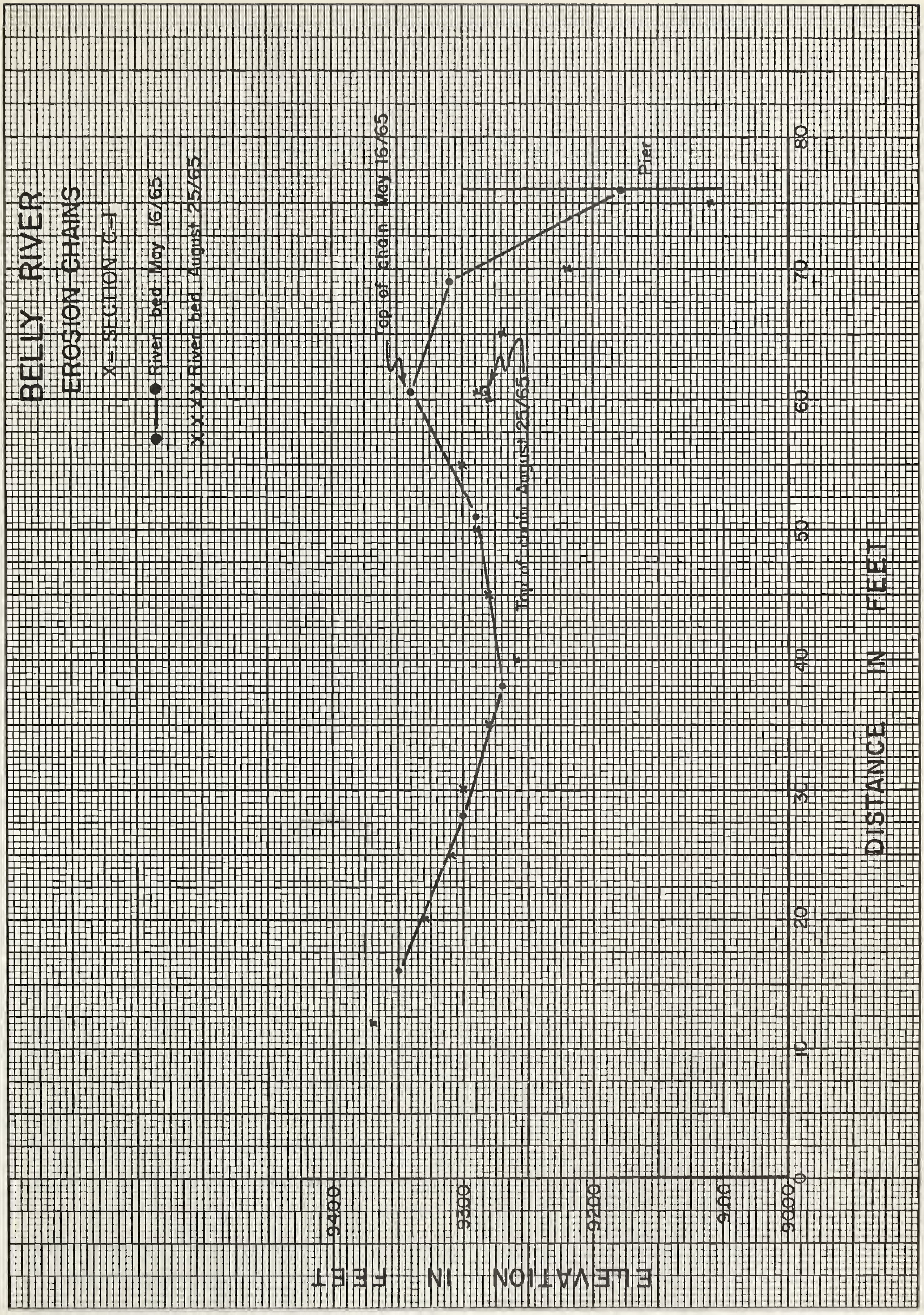

BELLY RIVER
EROSION CHAINS
X-SECTION C-1
●—● River bed May 16/65
XXXX River bed August 25/65
Top of chain May 16/65
Top of chain August 25/65
Pier
94.00
93.00
92.00
91.00
90.00
ELEVATION IN FEET
0
10
20
30
40
50
60
70
80
DISTANCE IN FEET

FIG. C2-34

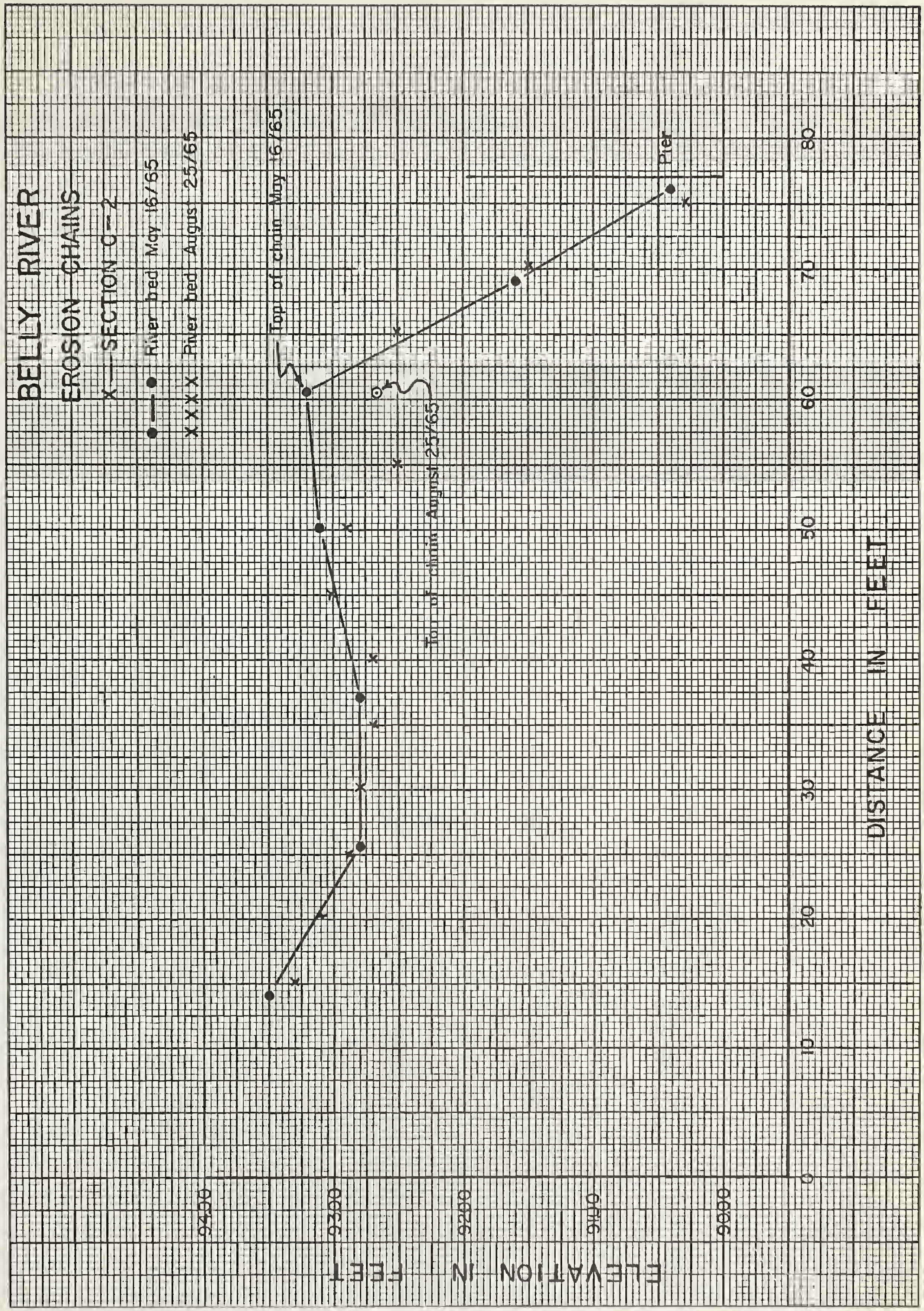

BELLY RIVER
EROSION CHAINS
X—SECTION C-2
●—● River bed May 16/65
XXXX River bed August 25/65
Top of chain May 16/65
Top of chain August 25/65
Pier
9400
9300
9200
9100
9000
ELEVATION IN FEET
0
10
20
30
40
50
60
70
80
DISTANCE IN FEET

FIG. C2-35

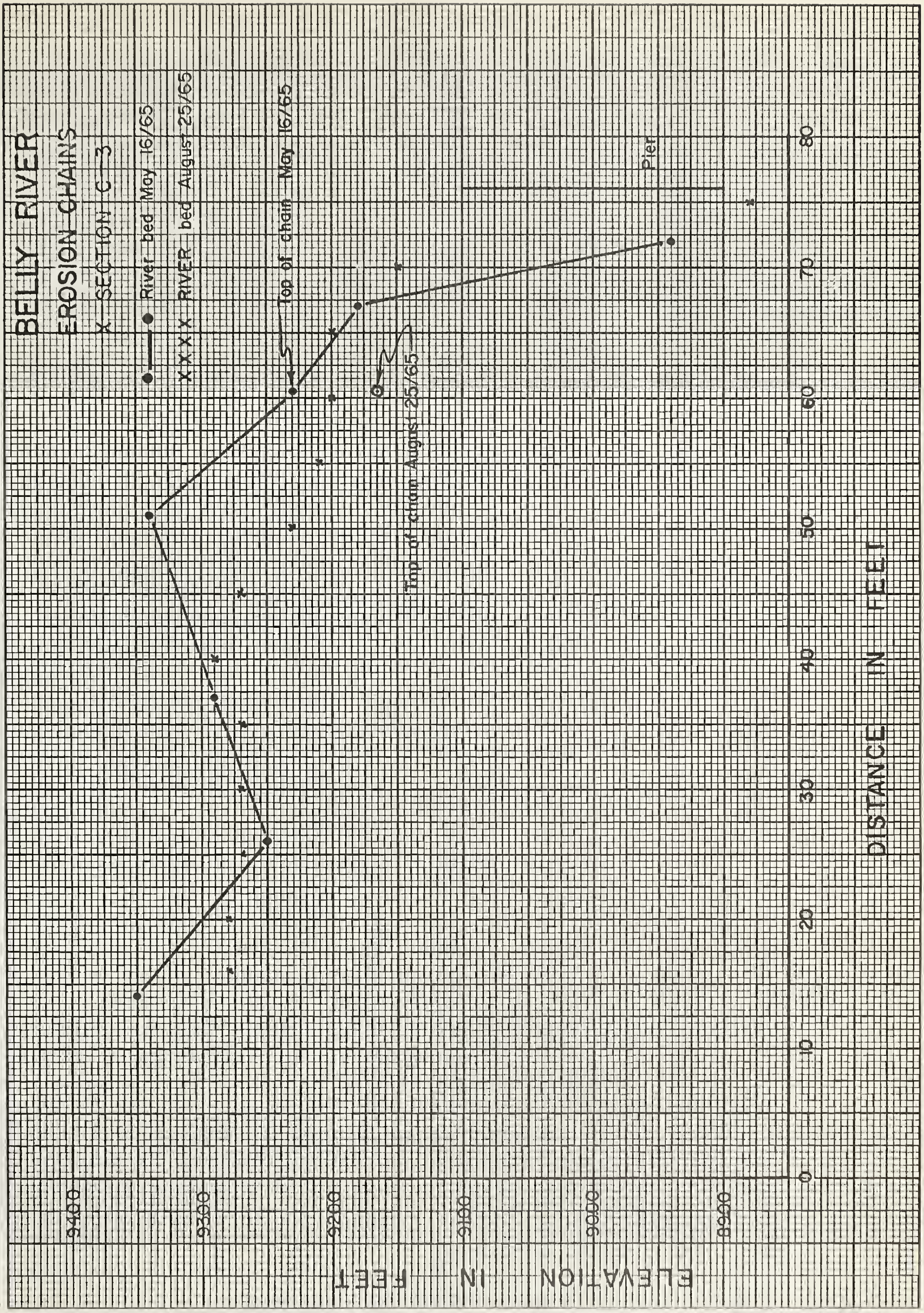

BELLY RIVER
EROSION CHAINS
X SECTION C-3
●—● River bed May 16/65
XXXX RIVER bed August 25/65
Top of chain May 16/65
Top of chain August 25/65
Pier
0
10
20
30
40
50
60
70
80
DISTANCE IN FEET
9400
9300
9200
9100
9000
8900
ELEVATION IN FEET

FIG. C2-36

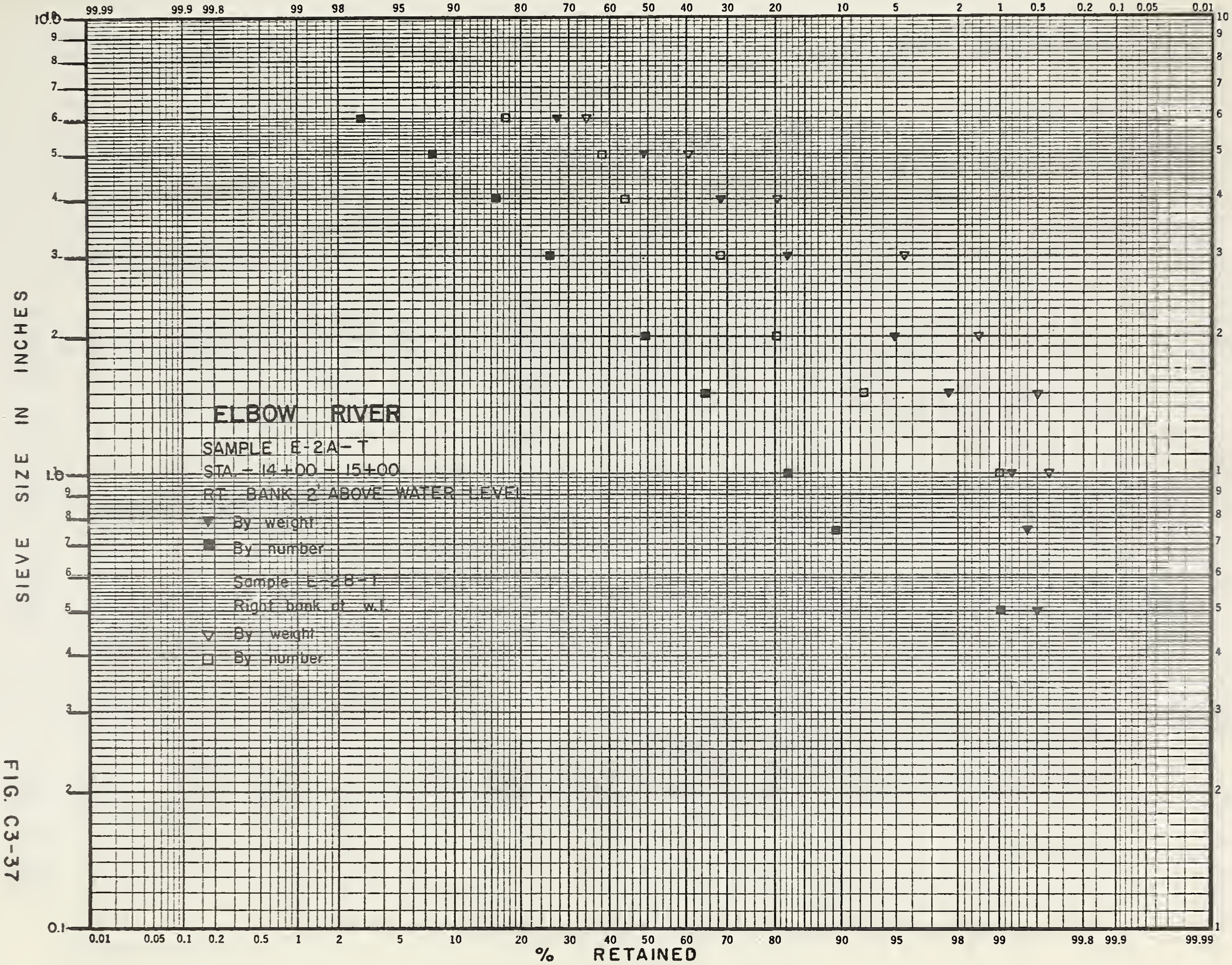

ELBOW RIVER
SAMPLE E-2A-T
STA. - 14+00 - 15+00
RT. BANK 2' ABOVE WATER LEVEL
▼ By weight
■ By number
Sample E-2B-T
Right bank at w.l.
▽ By weight
□ By number
SIEVE SIZE IN INCHES
% RETAINED
10.0
9
8
7
6
5
4
3
2
1.0
0.1
99.99
99.9
99.8
99
98
95
90
80
70
60
50
40
30
20
10
5
2
1
0.5
0.2
0.1
0.05
0.01

FIG. C3-37

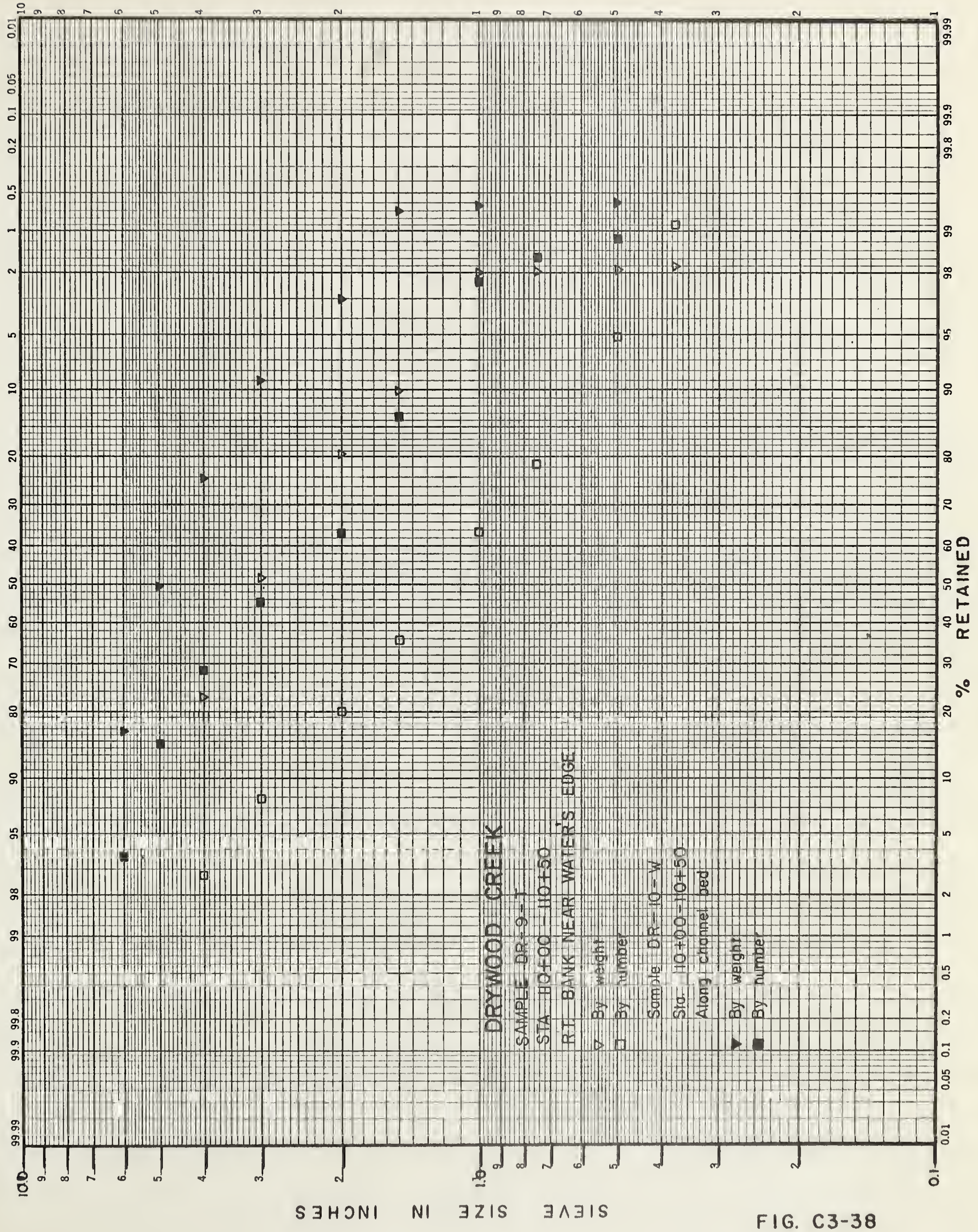

DRYWOOD CREEK
SAMPLE DR-9-T
STA 110+00 – 110+50
RT. BANK NEAR WATER'S EDGE
▽ By weight
□ By number
Sample DR-10-W
Sta. 110+00–110+50
Along channel bed
▼ By weight
■ By number
% RETAINED
SIEVE SIZE IN INCHES
10.0
1.0
0.1
99.99
99.9
99.8
99
98
95
90
80
70
60
50
40
30
20
10
5
2
1
0.5
0.2
0.1
0.05
0.01

FIG. C3-38

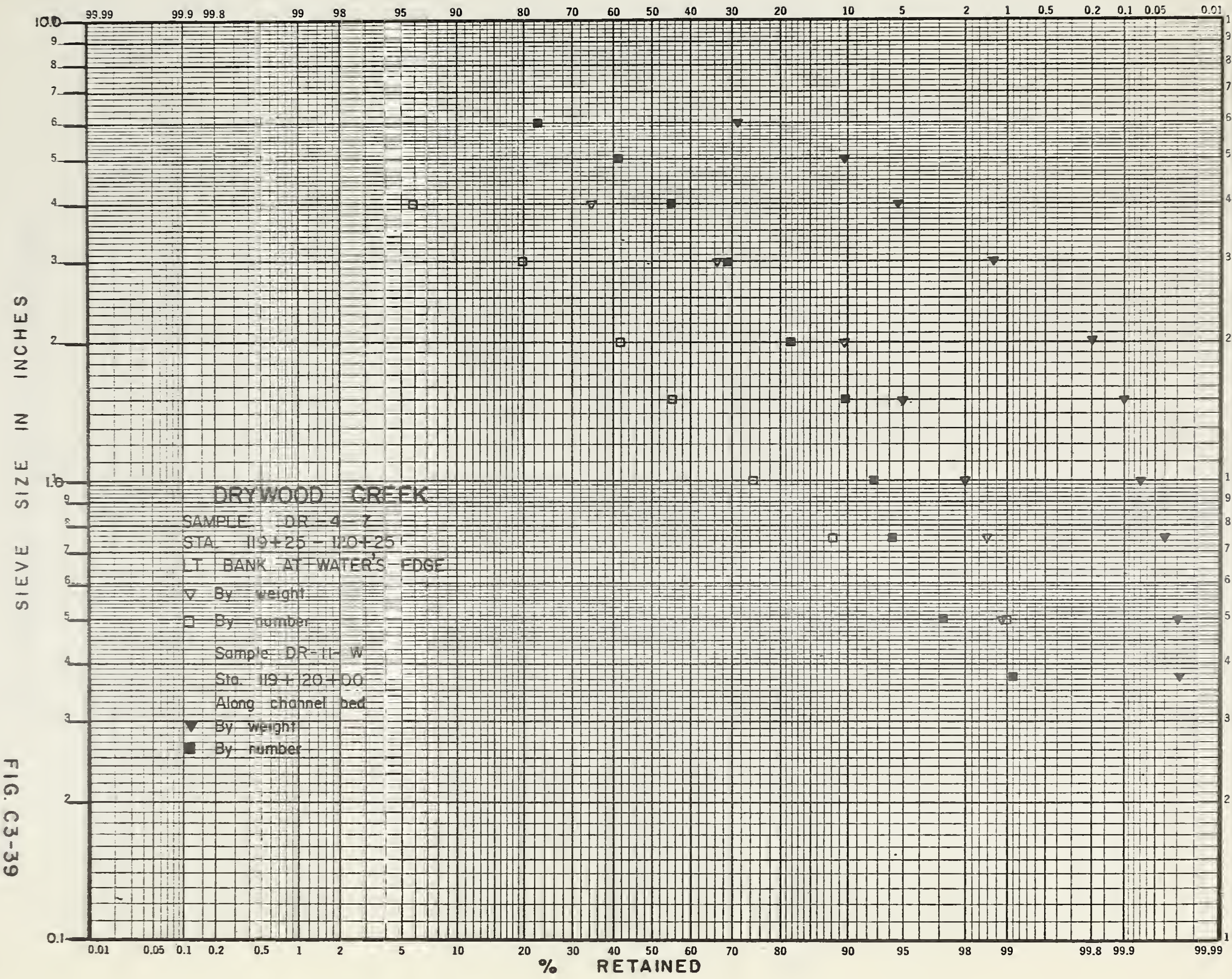

DRYWOOD CREEK
SAMPLE DR-4-7
STA. 119+25 – 120+25
LT. BANK AT WATER'S EDGE
▽ By weight
□ By number
Sample: DR-11-W
Sta. 119+20+00
Along channel bed
▼ By weight
■ By number
SIEVE SIZE IN INCHES
% RETAINED
10.0
1.0
0.1
99.99
99.9
99.8
99
98
95
90
80
70
60
50
40
30
20
10
5
2
1
0.5
0.2
0.1
0.05
0.01

FIG. C3-39

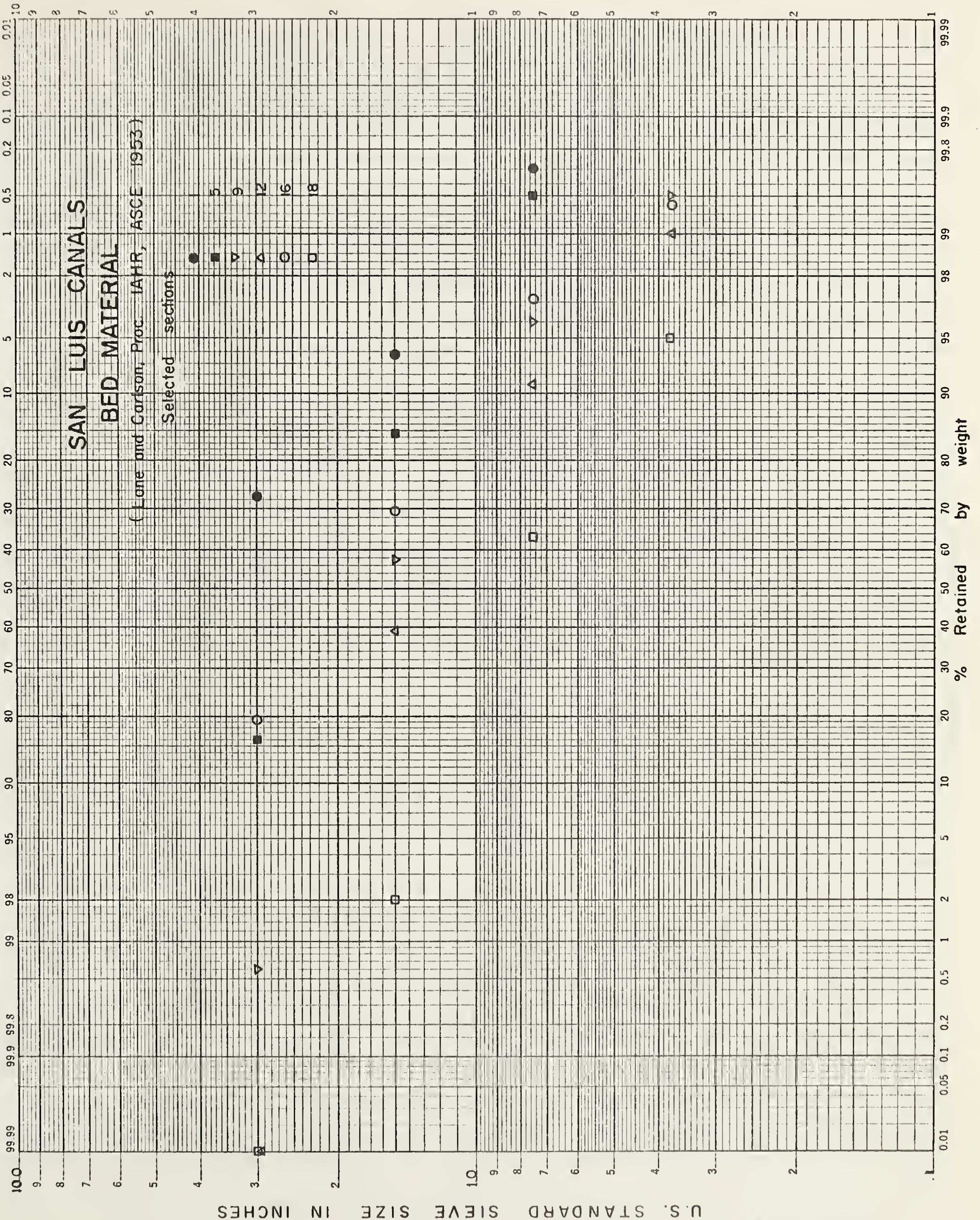

SAN LUIS CANALS
BED MATERIAL
(Lane and Carlson, Proc. IAHR, ASCE 1953)
Selected sections
● 1
■ 5
▽ 9
△ 12
○ 16
□ 18
% Retained by weight
U.S. STANDARD SIEVE SIZE IN INCHES
99.99 99.9 99.8 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.2 0.1 0.05 0.01
0.01 0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.8 99.9 99.99
10.0 9 8 7 6 5 4 3 2 1.0 9 8 7 6 5 4 3 2 1

FIG. C3-40

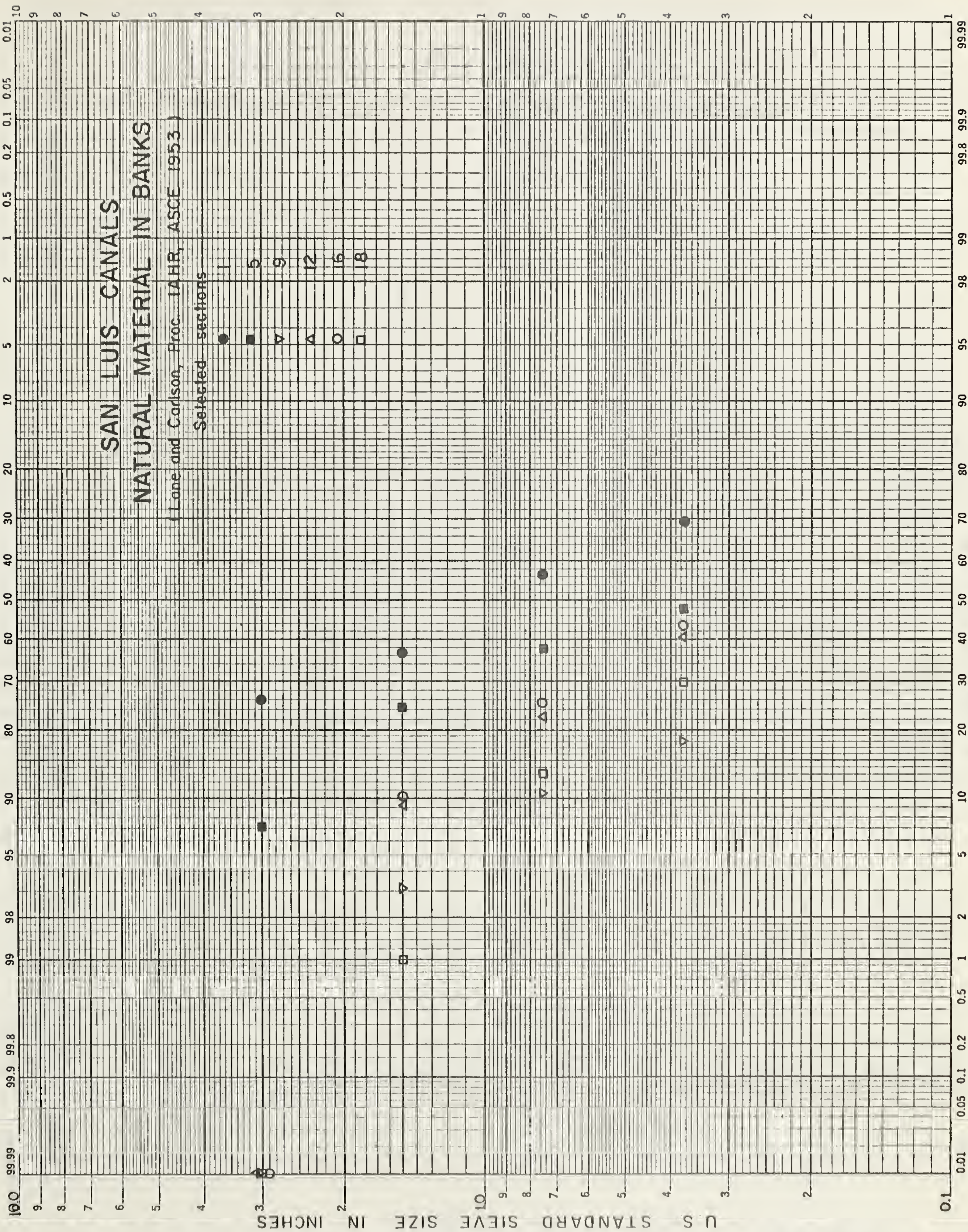

SAN LUIS CANALS
NATURAL MATERIAL IN BANKS
(Lane and Carlson, Proc. IAHR, ASCE 1953)
Selected sections
● 1
■ 5
▽ 9
△ 12
○ 16
□ 18
% Retained by weight
U.S. STANDARD SIEVE SIZE IN INCHES
10.0
1.0
0.1
0.01
0.05
0.1
0.2
0.5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.8
99.9
99.99

FIG. C3-41

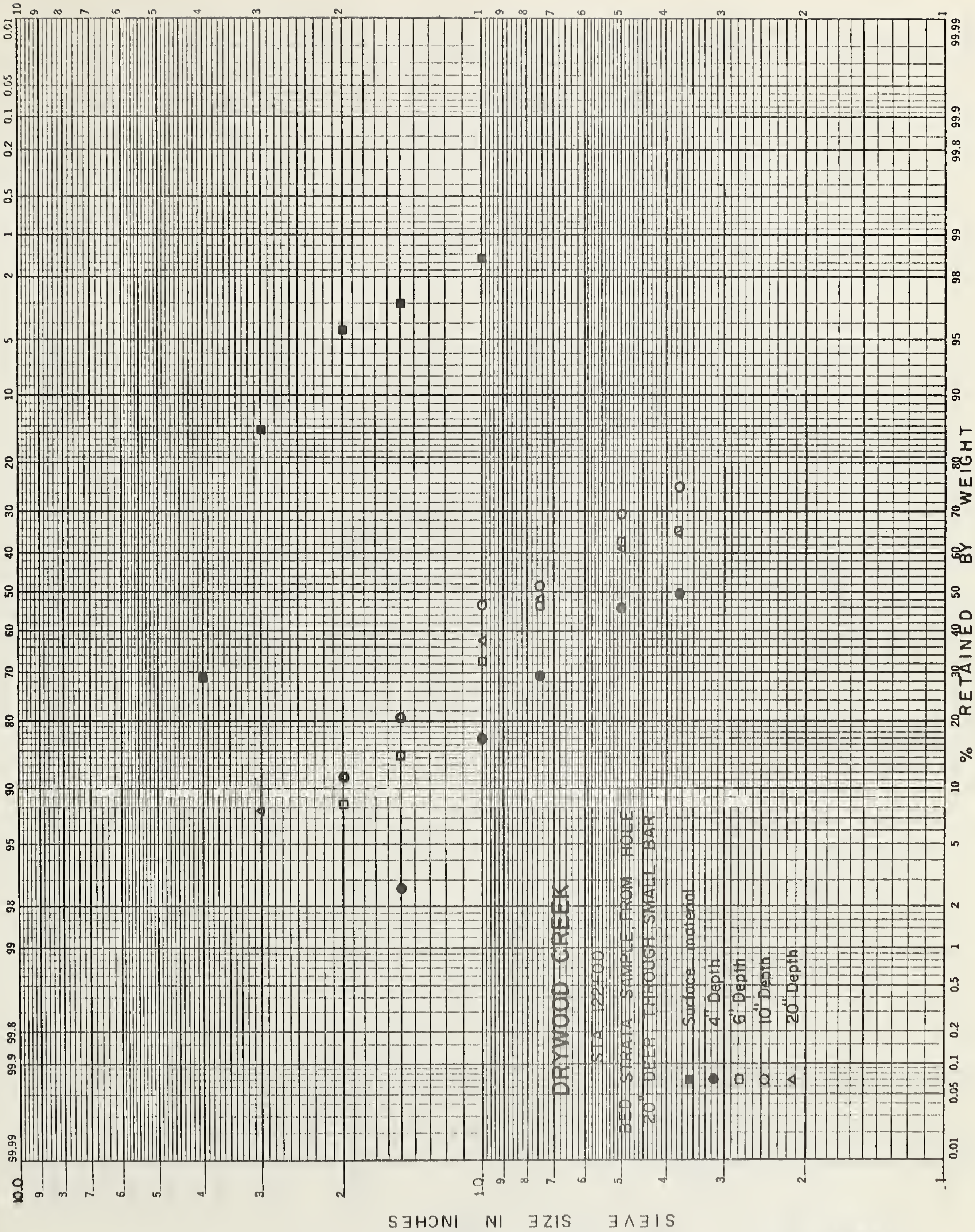
DRYWOOD CREEK
STA 122+00
BED STRATA SAMPLE FROM HOLE
20" DEEP THROUGH SMALL BAR
■ Surface material
● 4" Depth
□ 6" Depth
○ 10" Depth
△ 20" Depth
SIEVE SIZE IN INCHES
% RETAINED BY WEIGHT
10.0
9
8
7
6
5
4
3
2
1.0
.1
0.01
0.05
0.1
0.2
0.5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.8
99.9
99.99

FIG. C3-42

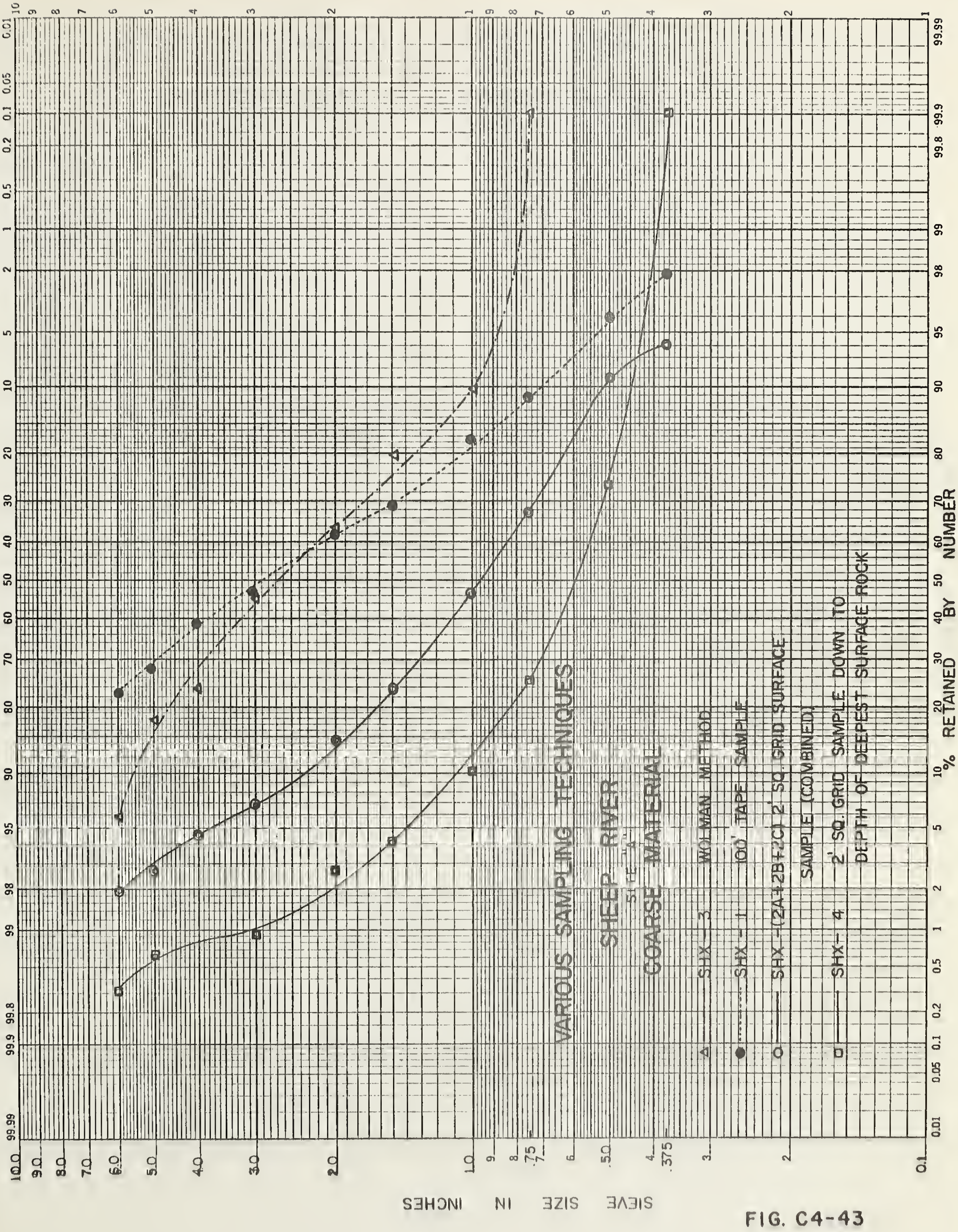

VARIOUS SAMPLING TECHNIQUES
SHEEP RIVER
SITE "A"
COARSE MATERIAL
△ SHX – 3 WOLMAN METHOD
● SHX – 1 100' TAPE SAMPLE
○ SHX – (2A+2B+2C) 2' SQ. GRID SURFACE SAMPLE (COMBINED)
□ SHX – 4 2' SQ. GRID SAMPLE DOWN TO DEPTH OF DEEPEST SURFACE ROCK
% RETAINED BY NUMBER
SIEVE SIZE IN INCHES
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
.75
.50
.375
0.1
99.99
99.9
99.8
99
98
95
90
80
70
60
50
40
30
20
10
5
2
1
0.5
0.2
0.1
0.05
0.01

FIG. C4-43

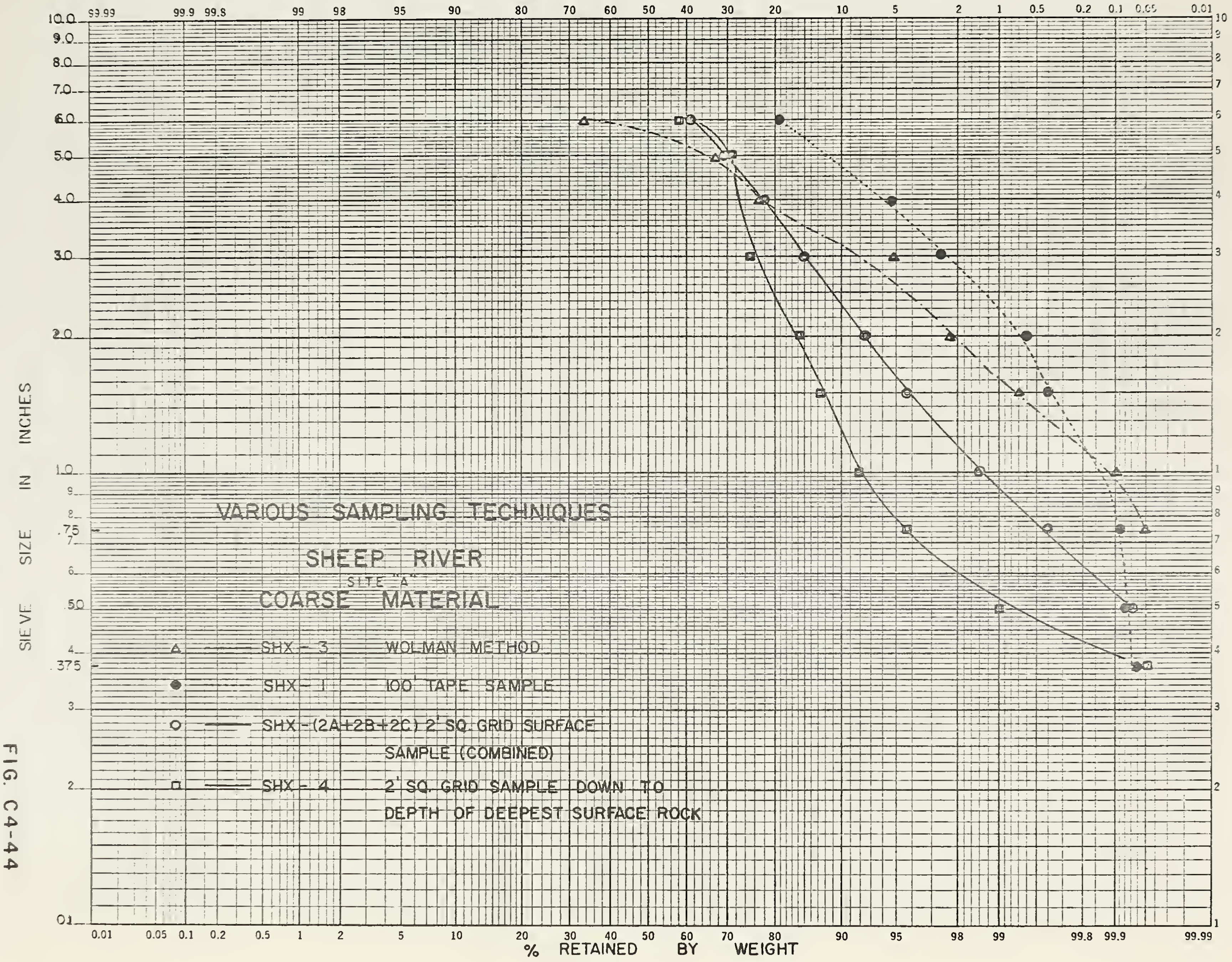

VARIOUS SAMPLING TECHNIQUES
SHEEP RIVER
SITE "A"
COARSE MATERIAL
△ SHX - 3 WOLMAN METHOD
● SHX - 1 100' TAPE SAMPLE
○ SHX -(2A+2B+2C) 2' SQ. GRID SURFACE SAMPLE (COMBINED)
□ SHX - 4 2' SQ. GRID SAMPLE DOWN TO DEPTH OF DEEPEST SURFACE ROCK
SIEVE SIZE IN INCHES
% RETAINED BY WEIGHT
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
.75
.50
.375
0.1
99.99
99.9
99.8
99
98
95
90
80
70
60
50
40
30
20
10
5
2
1
0.5
0.2
0.1
0.05
0.01

FIG. C4-44

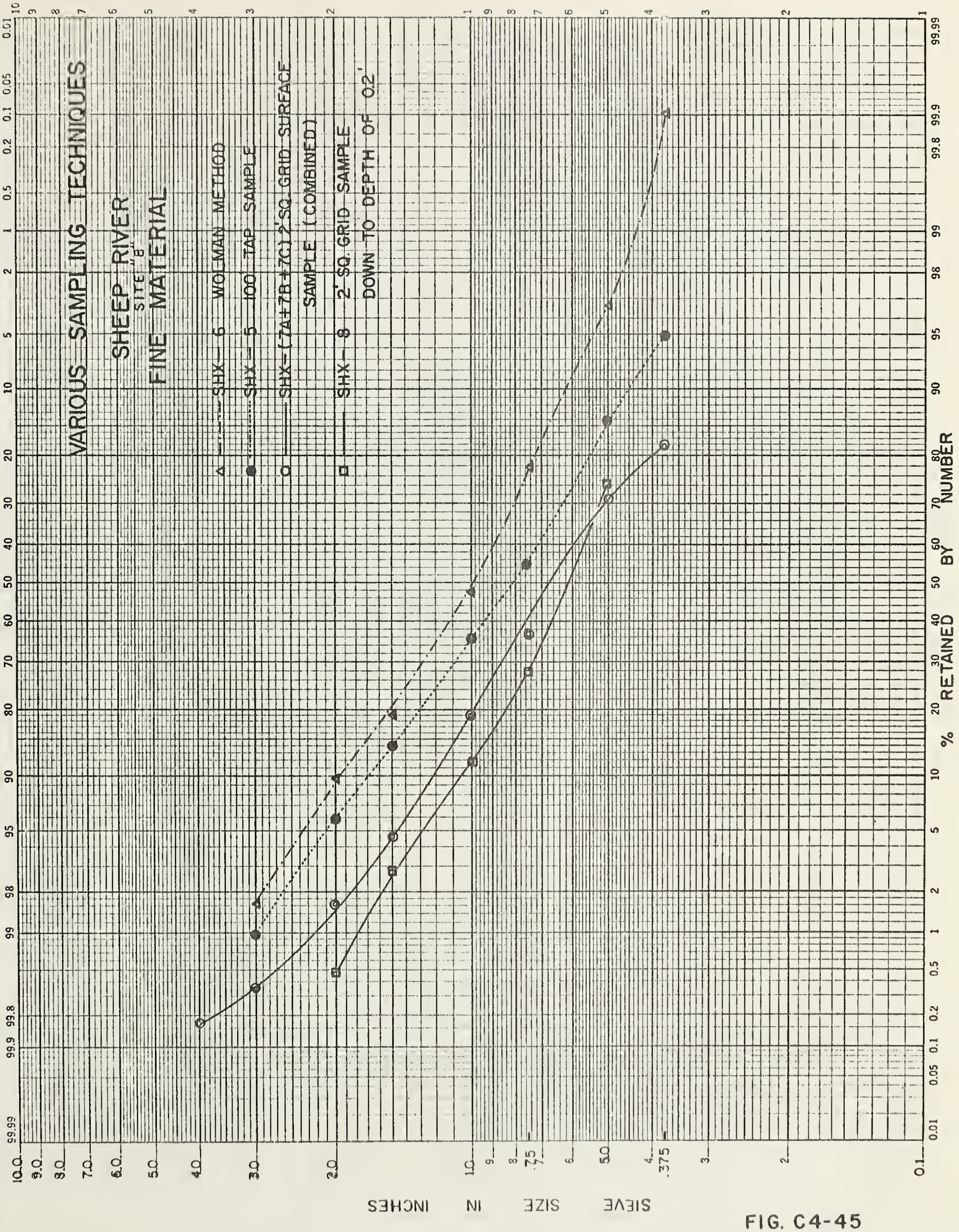

VARIOUS SAMPLING TECHNIQUES
SHEEP RIVER
SITE "B"
FINE MATERIAL
SHX – 6 WOLMAN METHOD
SHX – 5 100 TAP SAMPLE
SHX – (7A+7B+7C) 2' SQ. GRID SURFACE SAMPLE (COMBINED)
SHX – 8 2' SQ. GRID SAMPLE DOWN TO DEPTH OF 0.2'
SIEVE SIZE IN INCHES
% RETAINED BY NUMBER
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
.75
5.0
.375
0.1
0.01
0.05
0.1
0.2
0.5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.8
99.9
99.99

FIG. C4-45

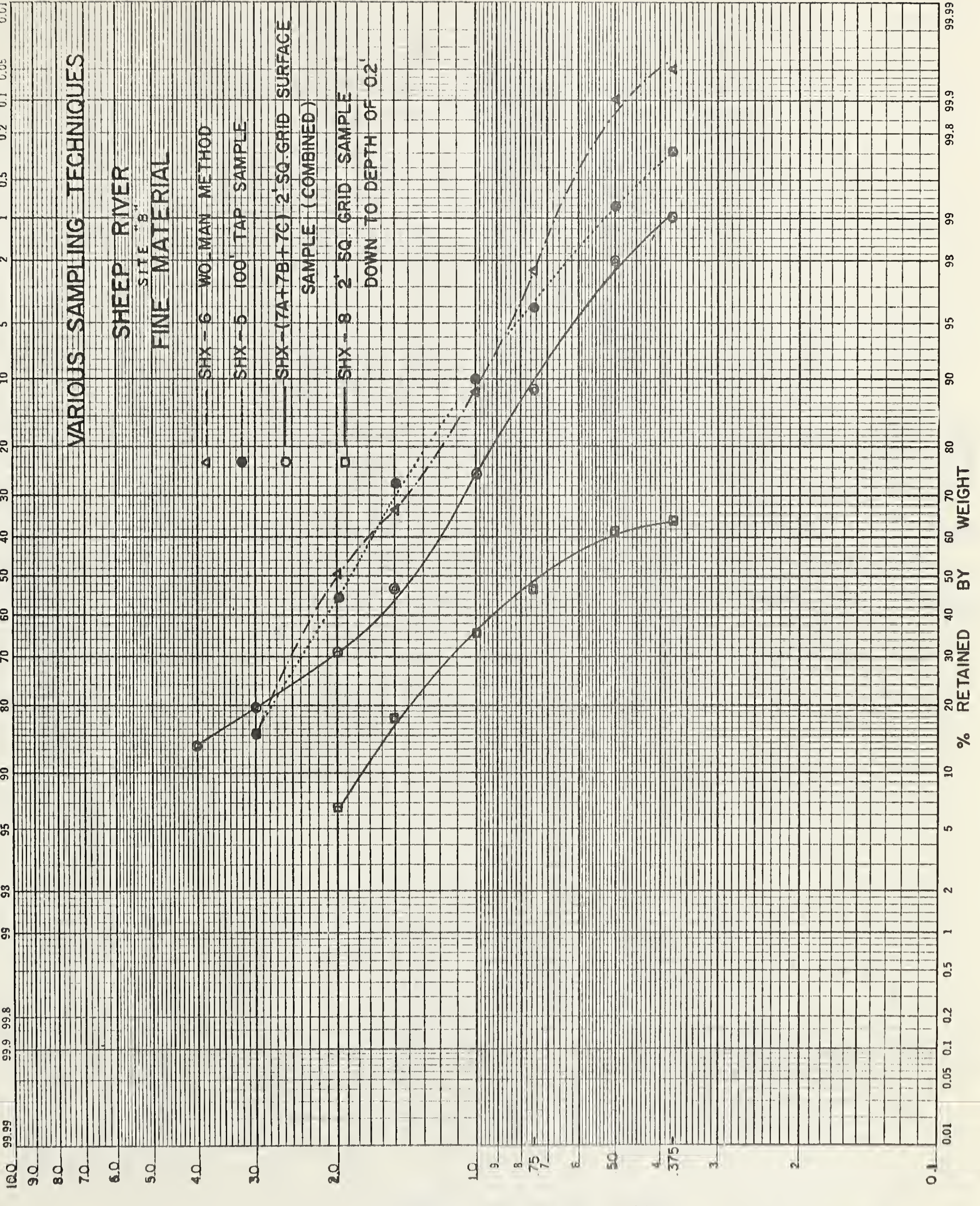

VARIOUS SAMPLING TECHNIQUES
SHEEP RIVER
SITE "B"
FINE MATERIAL
△ SHX - 6 WOLMAN METHOD
● SHX - 5 100' TAP SAMPLE
○ SHX - (7A+7B+7C) 2' 2' SQ. GRID SURFACE SAMPLE (COMBINED)
□ SHX - 8 2' SQ. GRID SAMPLE DOWN TO DEPTH OF 0.2'
% RETAINED BY WEIGHT
SIEVE SIZE IN INCHES
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
.75
.50
.375
0.1
0.01
0.05
0.1
0.2
0.5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.8
99.9
99.99

FIG. C4-46

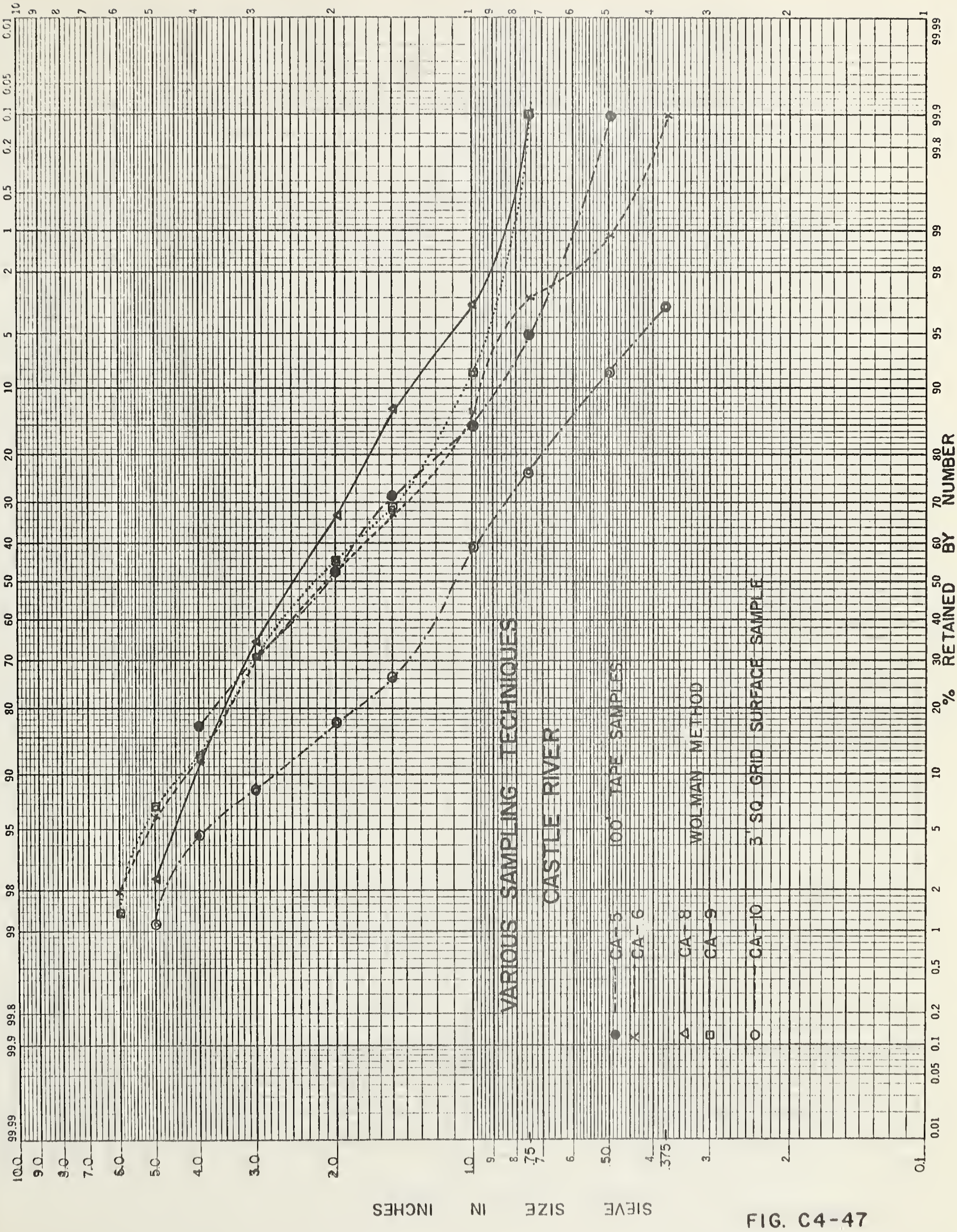
VARIOUS SAMPLING TECHNIQUES
CASTLE RIVER
● CA-5 100' TAPE SAMPLES
x CA-6
△ CA-8 WOLMAN METHOD
⊡ CA-9
○ CA-10 3' SQ. GRID SURFACE SAMPLE
% RETAINED BY NUMBER
SIEVE SIZE IN INCHES
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
.75
.50
.375
0.1
99.99
99.9
99.8
99
98
95
90
80
70
60
50
40
30
20
10
5
2
1
0.5
0.2
0.1
0.05
0.01

FIG. C4-47

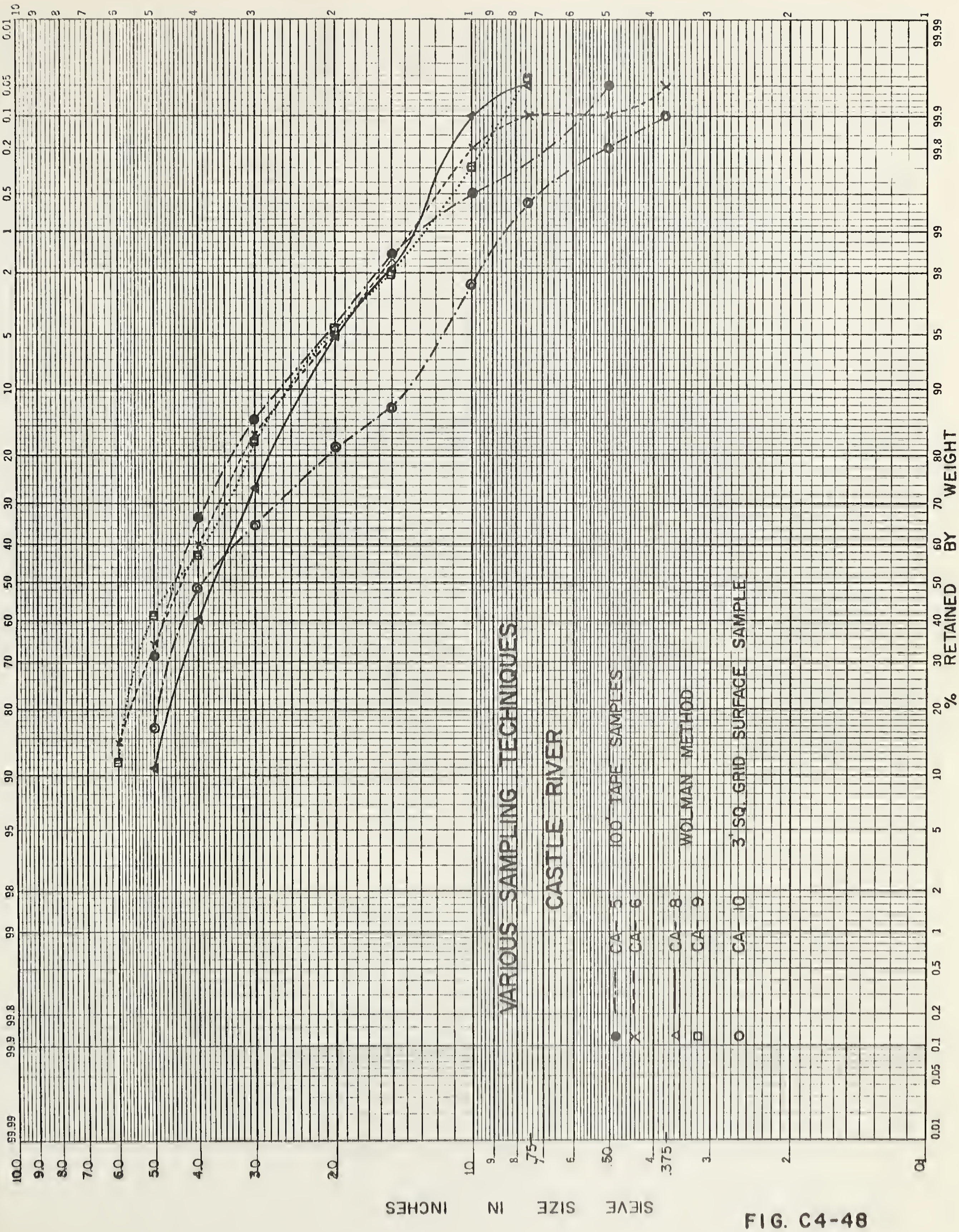

VARIOUS SAMPLING TECHNIQUES
CASTLE RIVER
● CA - 5 } 100' TAPE SAMPLES
X CA - 6 } 100' TAPE SAMPLES
△ CA - 8 } WOLMAN METHOD
□ CA - 9 } WOLMAN METHOD
○ CA - 10 3' SQ. GRID SURFACE SAMPLE
SIEVE SIZE IN INCHES
% RETAINED BY WEIGHT
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
.75
.50
.375
0.01
0.05
0.1
0.2
0.5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.8
99.9
99.99

FIG. C4-48

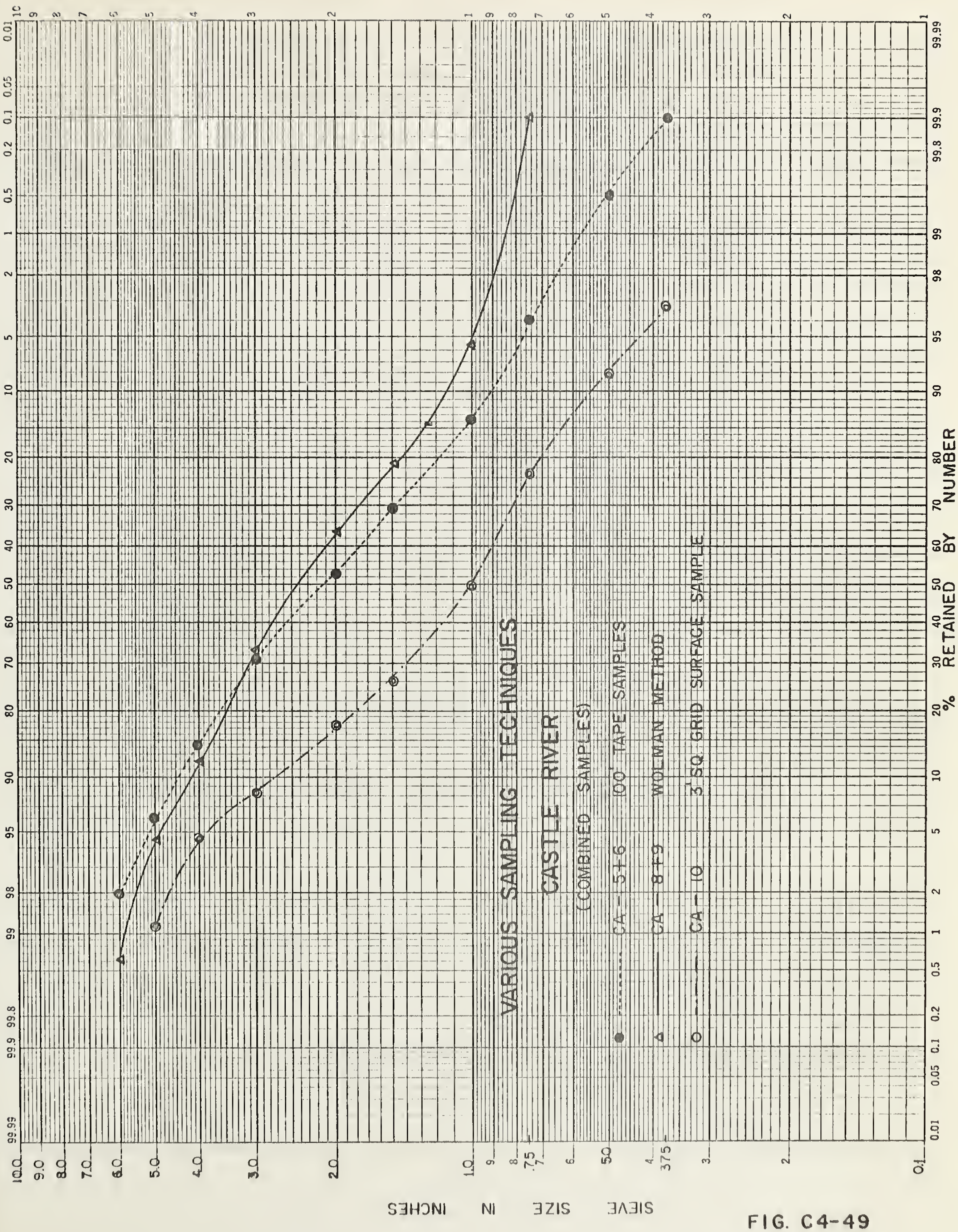

VARIOUS SAMPLING TECHNIQUES
CASTLE RIVER
(COMBINED SAMPLES)
● ------- CA – 5+6 100' TAPE SAMPLES
△ ——— CA – 8+9 WOLMAN METHOD
○ —·—·— CA – 10 3' SQ. GRID SURFACE SAMPLE
% RETAINED BY NUMBER
SIEVE SIZE IN INCHES
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
.75
.50
.375
0.1
99.99
99.9
99.8
99
98
95
90
80
70
60
50
40
30
20
10
5
2
1
0.5
0.2
0.1
0.05
0.01

FIG. C4-49

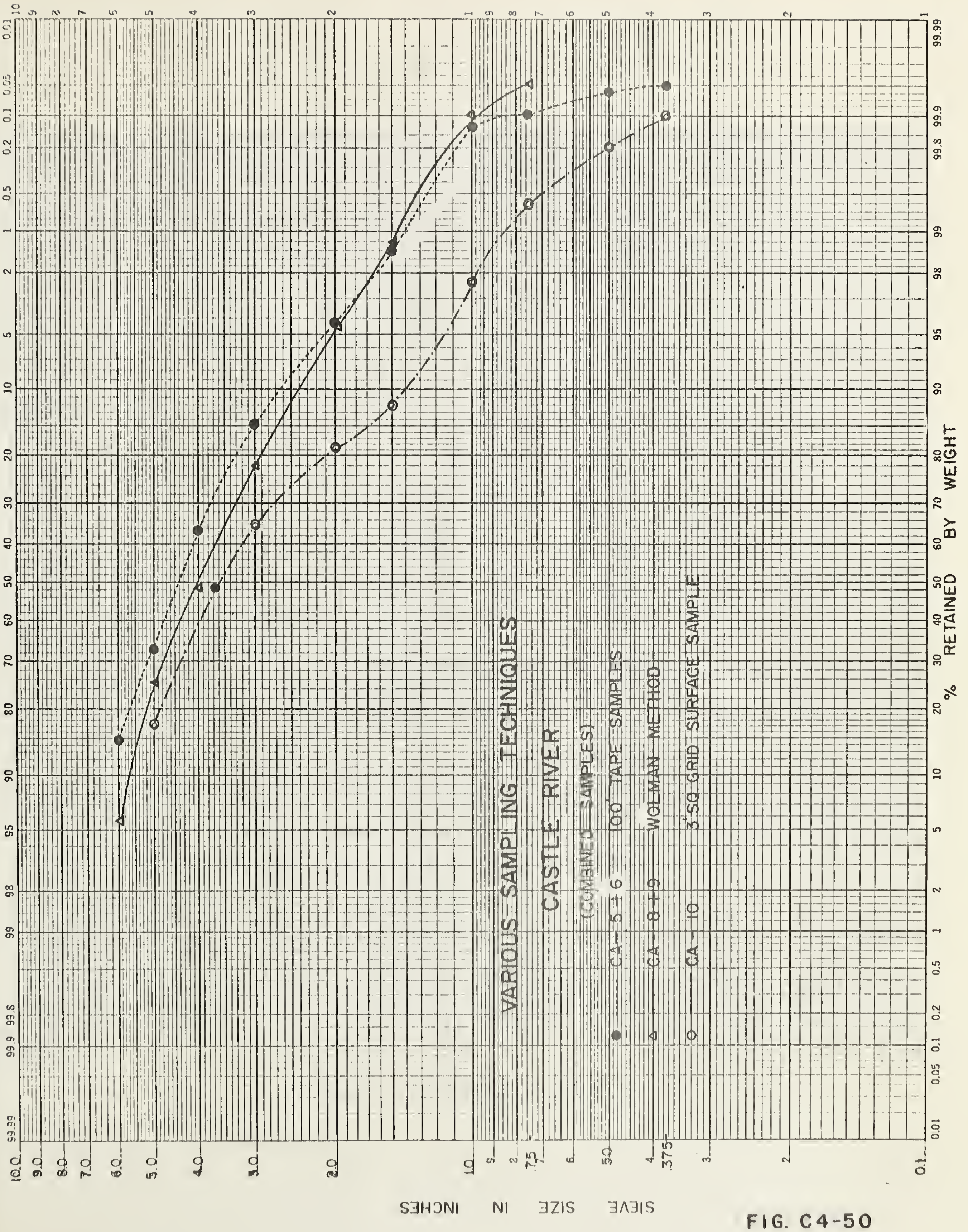
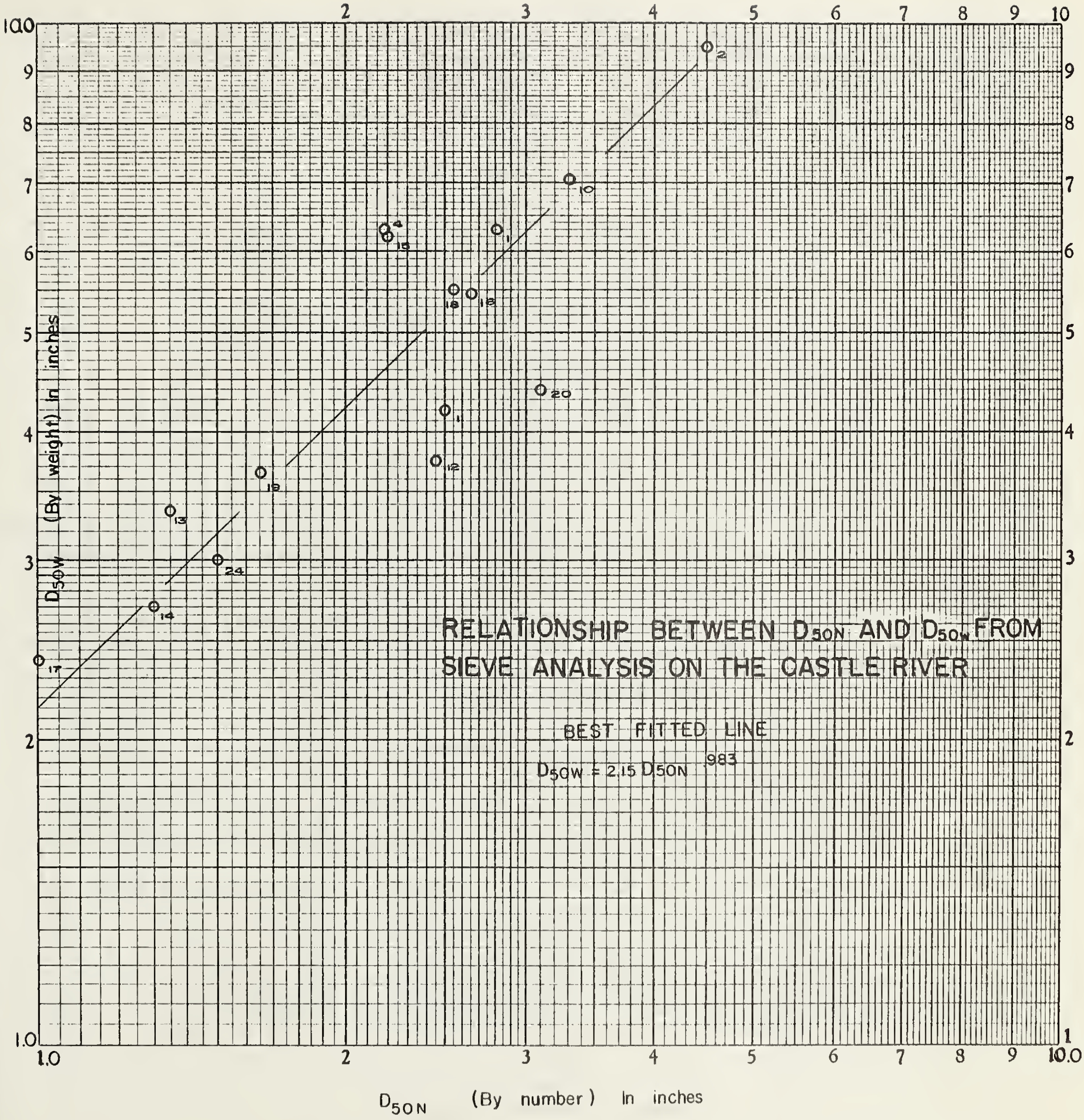

VARIOUS SAMPLING TECHNIQUES
CASTLE RIVER
(COMBINED SAMPLES)
● CA – 5 + 6 100' TAPE SAMPLES
△ CA 8 + 9 WOLMAN METHOD
○ CA – 10 3' SQ. GRID SURFACE SAMPLE
% RETAINED BY WEIGHT
SIEVE SIZE IN INCHES
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
.9
.8
.75
.6
.50
.4
.375
.3
.2
0.1
99.99
99.9
99.8
99
98
95
90
80
70
60
50
40
30
20
10
5
2
1
0.5
0.2
0.1
0.05
0.01

FIG. C4-50

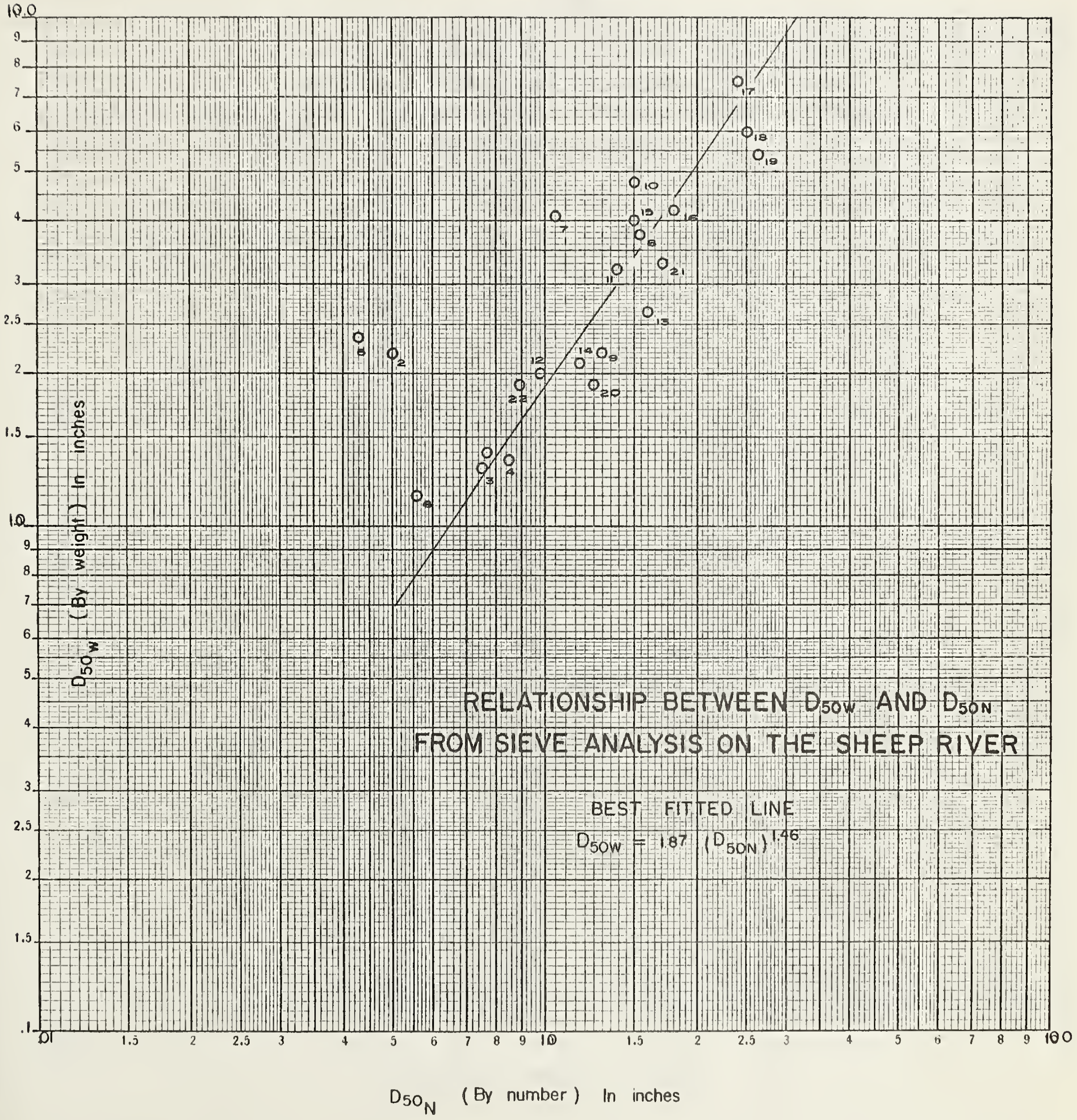


RELATIONSHIP BETWEEN D_{50N} AND D_{50W} FROM SIEVE ANALYSIS ON THE CASTLE RIVER

BEST FITTED LINE

$D_{50W} = 2.15\, D_{50N}^{\;.983}$

FIG. C5-51

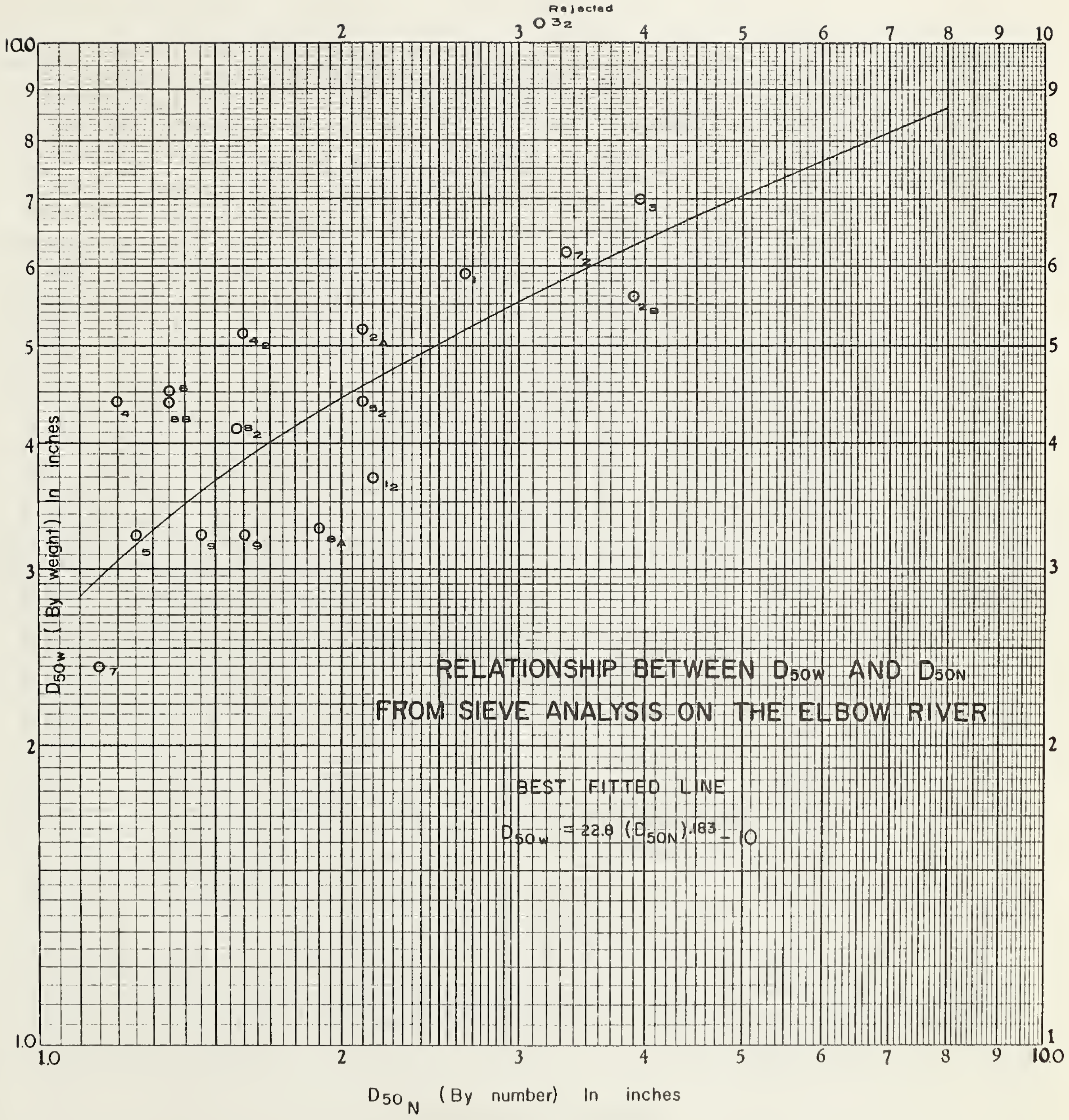


RELATIONSHIP BETWEEN D_{50W} AND D_{50N} FROM SIEVE ANALYSIS ON THE SHEEP RIVER

BEST FITTED LINE

$D_{50W} = 1.87\ (D_{50N})^{1.46}$

FIG. C5-52

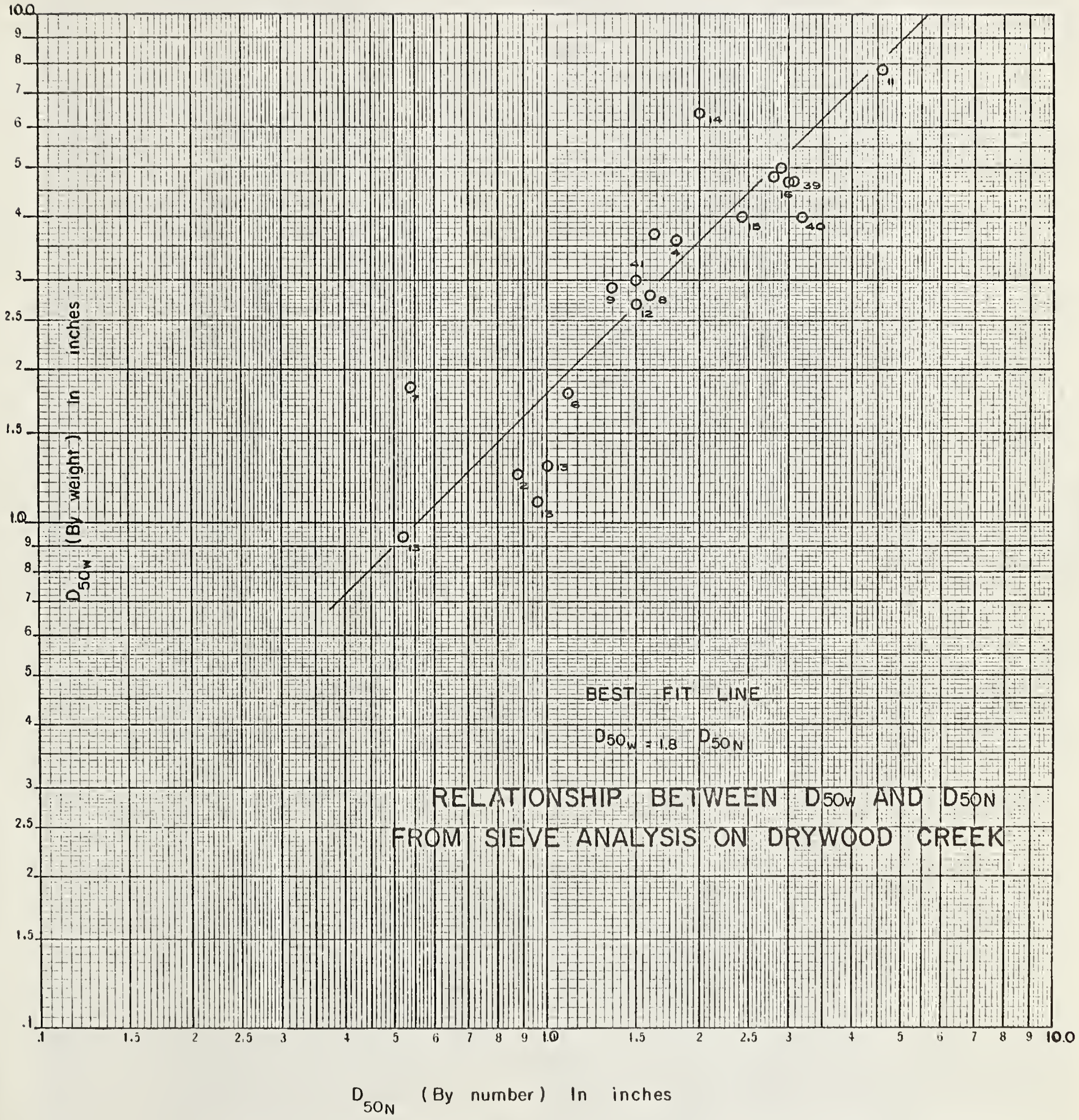


RELATIONSHIP BETWEEN D_{50W} AND D_{50N} FROM SIEVE ANALYSIS ON THE ELBOW RIVER

BEST FITTED LINE

$D_{50w} = 22.8\,(D_{50N})^{.183} - 10$

FIG. C5-53



RELATIONSHIP BETWEEN D_{50W} AND D_{50N} FROM SIEVE ANALYSIS ON DRYWOOD CREEK

FIG. C5-54

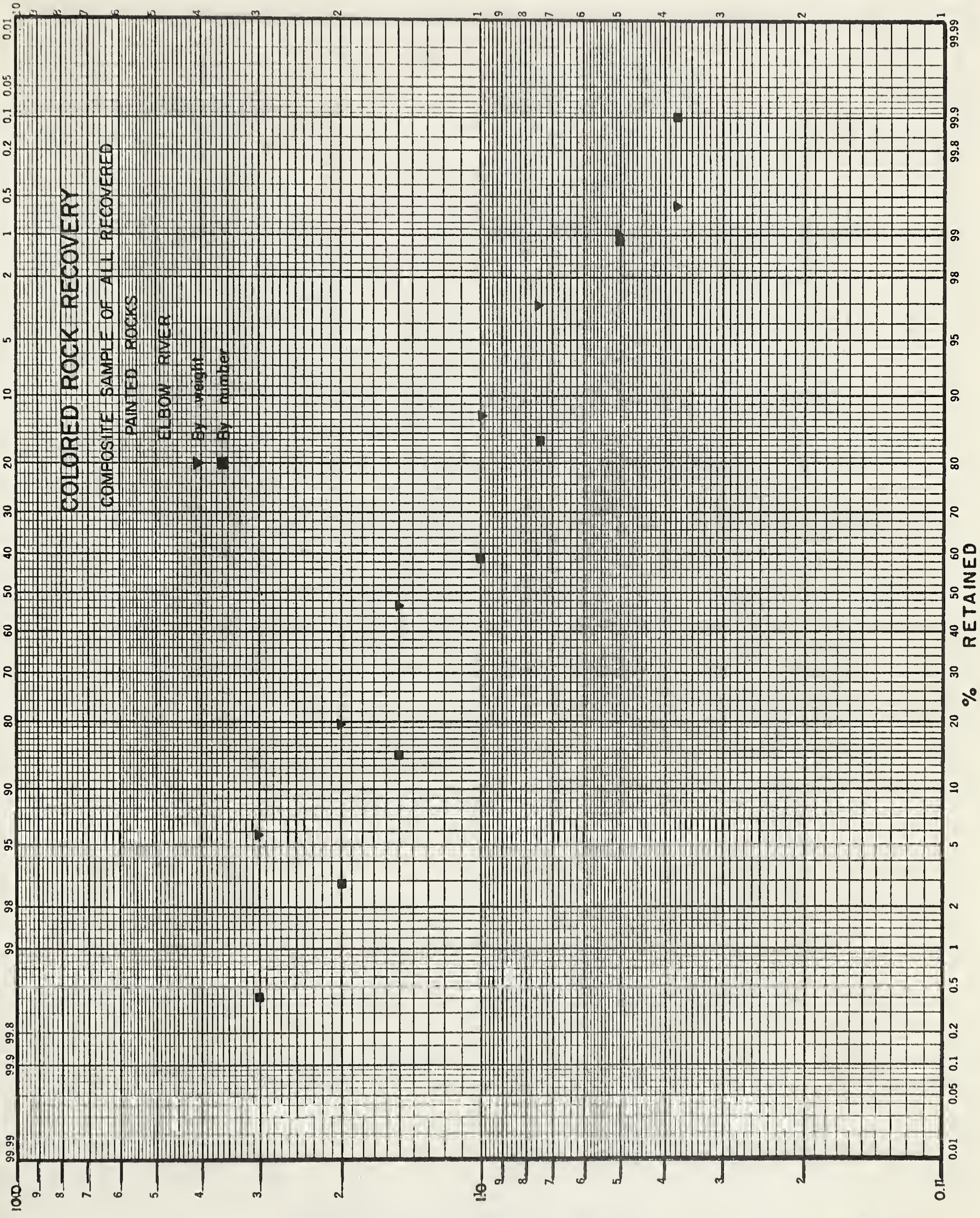

COLORED ROCK RECOVERY
COMPOSITE SAMPLE OF ALL RECOVERED
PAINTED ROCKS
ELBOW RIVER
▼ By weight
■ By number
% RETAINED
SIEVE SIZE IN INCHES
10.0
1.0
0.1

FIG. C6-55

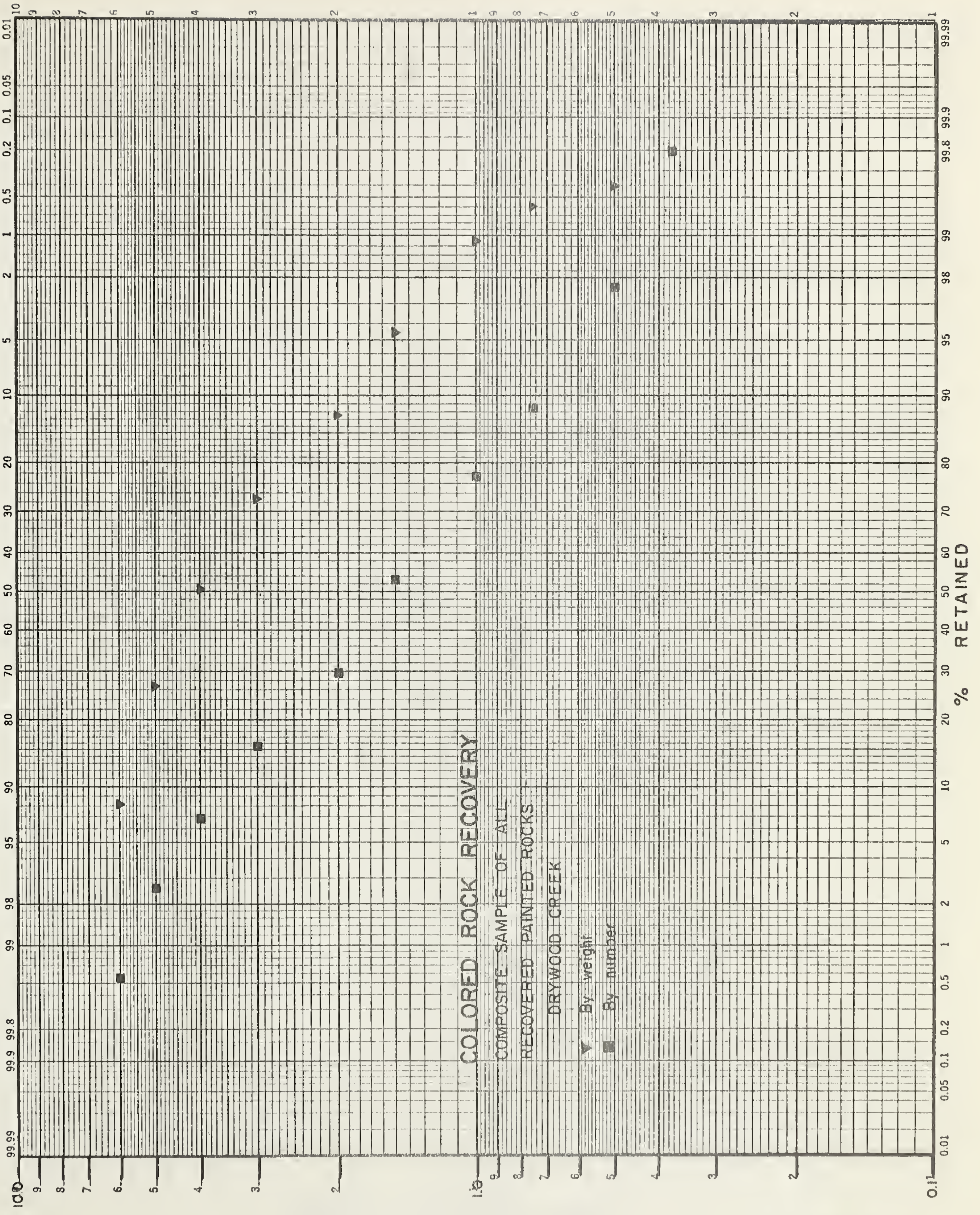

COLORED ROCK RECOVERY
COMPOSITE SAMPLE OF ALL
RECOVERED PAINTED ROCKS
DRYWOOD CREEK
▼ By weight
■ By number
SIEVE SIZE IN INCHES
% RETAINED
10.0
1.0
0.1
0.01
0.05
0.1
0.2
0.5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.8
99.9
99.99

FIG. C6-56

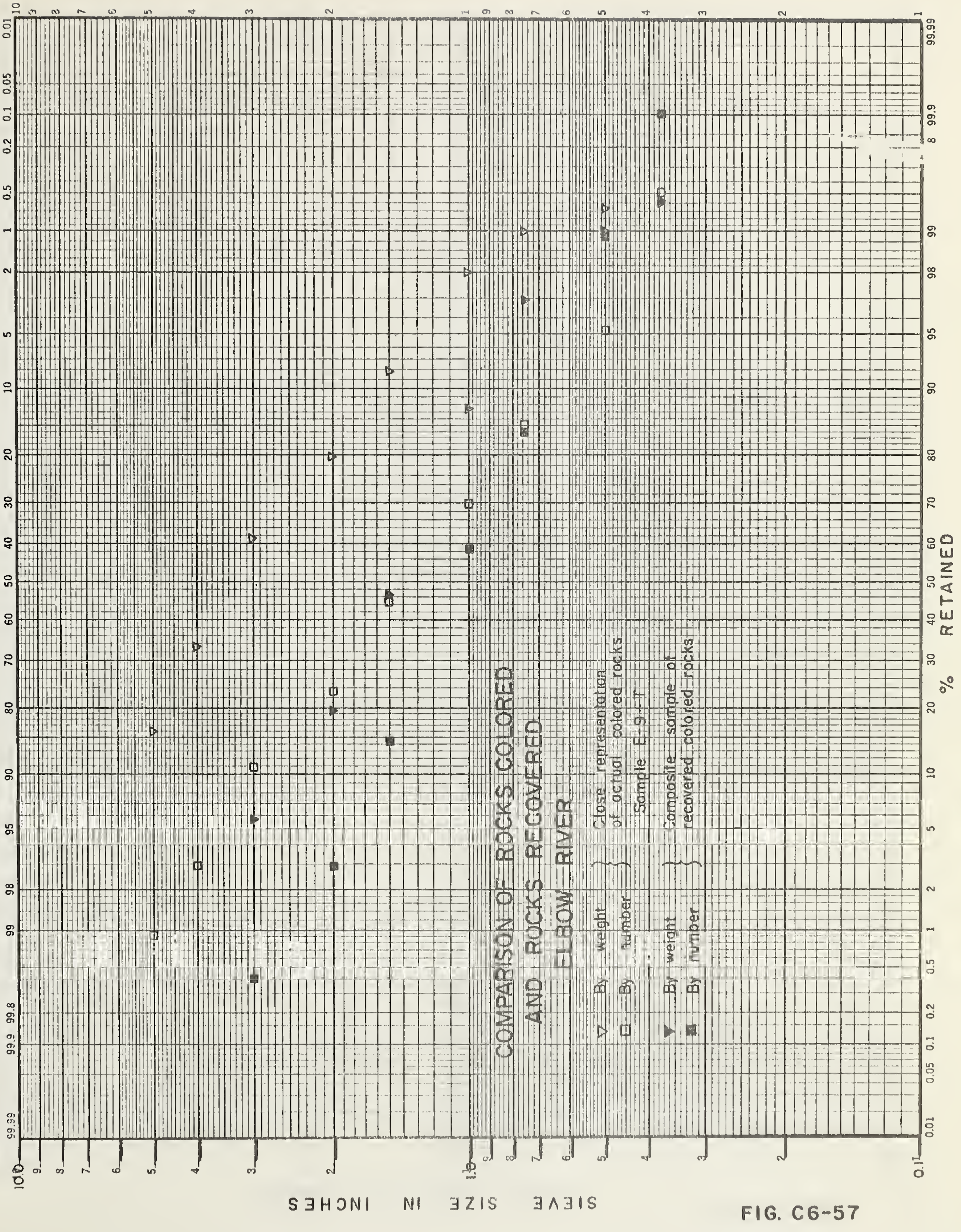

COMPARISON OF ROCKS COLORED
AND ROCKS RECOVERED
ELBOW RIVER
▽ By weight
□ By number
Close representation of actual colored rocks
Sample E-9-T
▼ By weight
■ By number
Composite sample of recovered colored rocks
% RETAINED
SIEVE SIZE IN INCHES
10.0
1.0
0.1
0.01
0.05
0.1
0.2
0.5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.8
99.9
99.99

FIG. C6-57

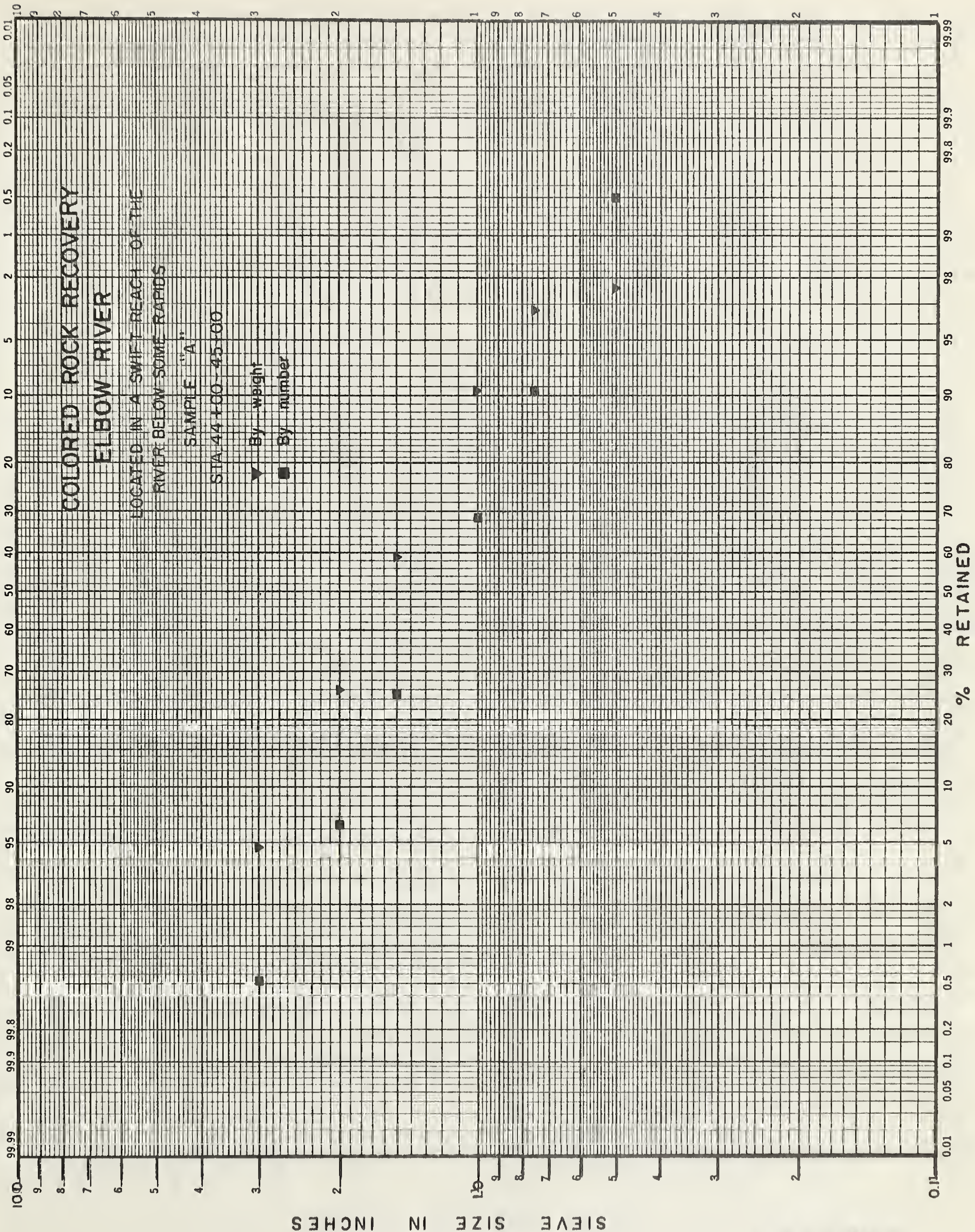

COLORED ROCK RECOVERY
ELBOW RIVER
LOCATED IN A SWIFT REACH OF THE
RIVER BELOW SOME RAPIDS
SAMPLE "A"
STA 44+00 - 45+00
▼ By weight
■ By number
% RETAINED
SIEVE SIZE IN INCHES
10.0
1.0
0.1
0.01
0.05
0.1
0.2
0.5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.8
99.9
99.99

FIG. C6-58

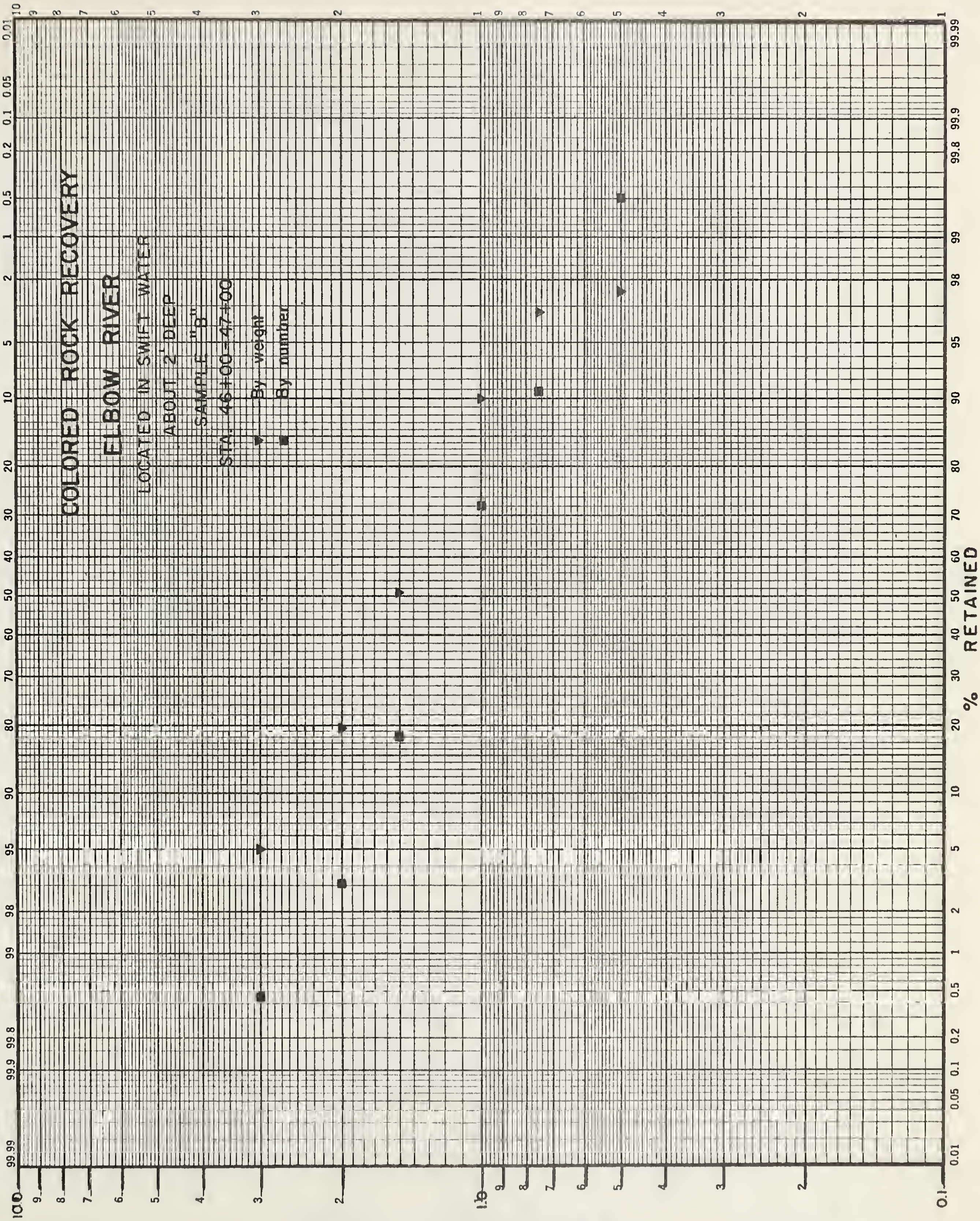

COLORED ROCK RECOVERY
ELBOW RIVER
LOCATED IN SWIFT WATER
ABOUT 2' DEEP
SAMPLE "B"
STA. 46+00-47+00
▼ By weight
■ By number
SIEVE SIZE IN INCHES
% RETAINED
10.0
1.0
0.1
9
8
7
6
5
4
3
2
99.99
99.9
99.8
99
98
95
90
80
70
60
50
40
30
20
10
5
2
1
0.5
0.2
0.1
0.05
0.01

FIG. C6-59

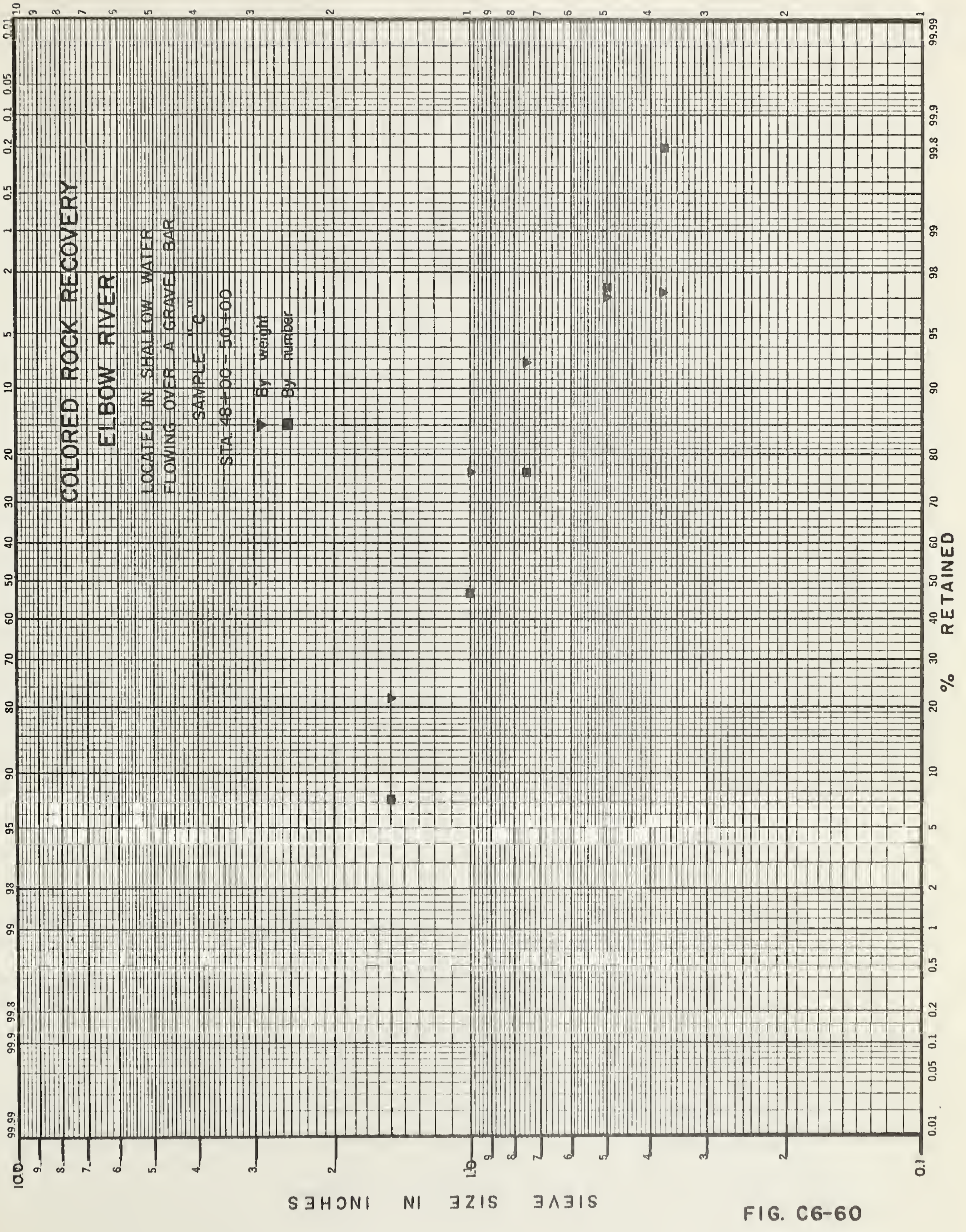

COLORED ROCK RECOVERY
ELBOW RIVER
LOCATED IN SHALLOW WATER
FLOWING OVER A GRAVEL BAR
SAMPLE "C"
STA. 48+00 - 50+00
▼ By weight
■ By number
% RETAINED
SIEVE SIZE IN INCHES
10.0
1.0
0.1
0.01
0.05
0.1
0.2
0.5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.8
99.9
99.99

FIG. C6-60

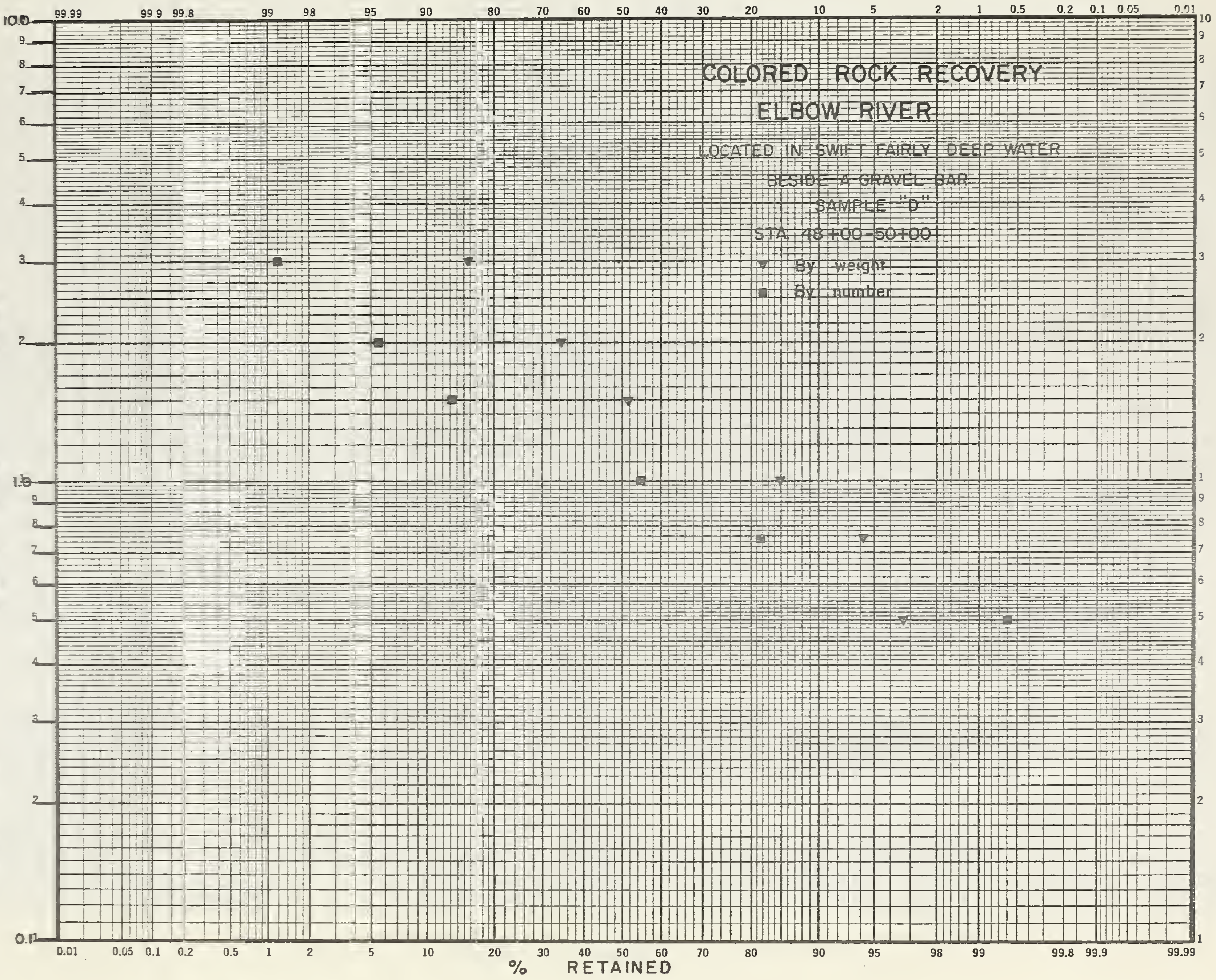

COLORED ROCK RECOVERY
ELBOW RIVER
LOCATED IN SWIFT FAIRLY DEEP WATER
BESIDE A GRAVEL BAR
SAMPLE "D"
STA. 48+00-50+00
▼ By weight
■ By number
SIEVE SIZE IN INCHES
% RETAINED
10.0
9
8
7
6
5
4
3
2
1.0
0.1
0.01
0.05
0.1
0.2
0.5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.8
99.9
99.99

FIG. C6-61

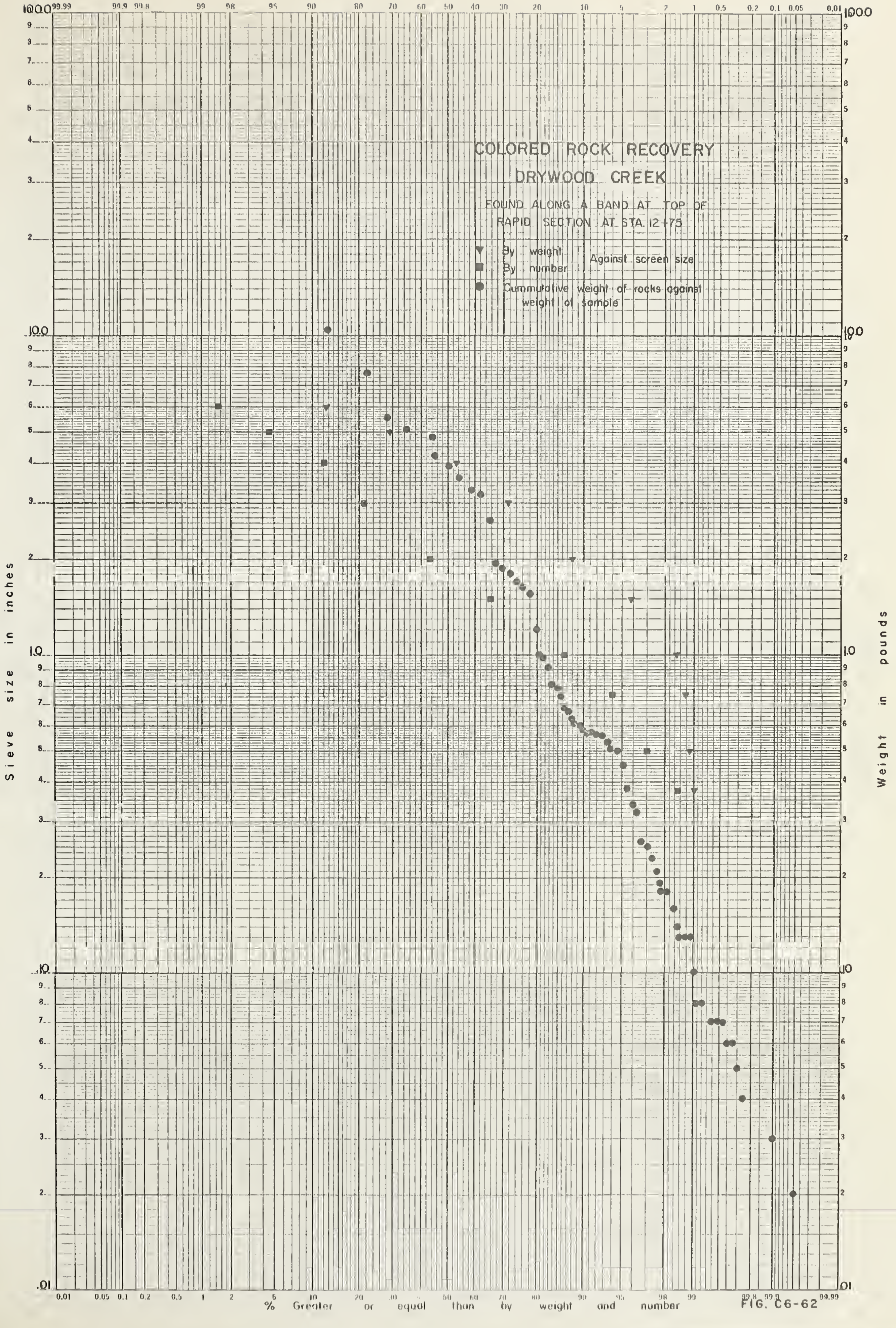

COLORED ROCK RECOVERY
DRYWOOD CREEK
FOUND ALONG A BAND AT TOP OF RAPID SECTION AT STA. 12+75
▼ By weight
■ By number
Against screen size
● Cummulative weight of rocks against weight of sample
Sieve size in inches
Weight in pounds
% Greater or equal than by weight and number
100.0
10.0
1.0
.10
.01
1000
100
10
1.0
.01
99.99
99.9
99.8
99
98
95
90
80
70
60
50
40
30
20
10
5
2
1
0.5
0.2
0.1
0.05
0.01

FIG. C6-62

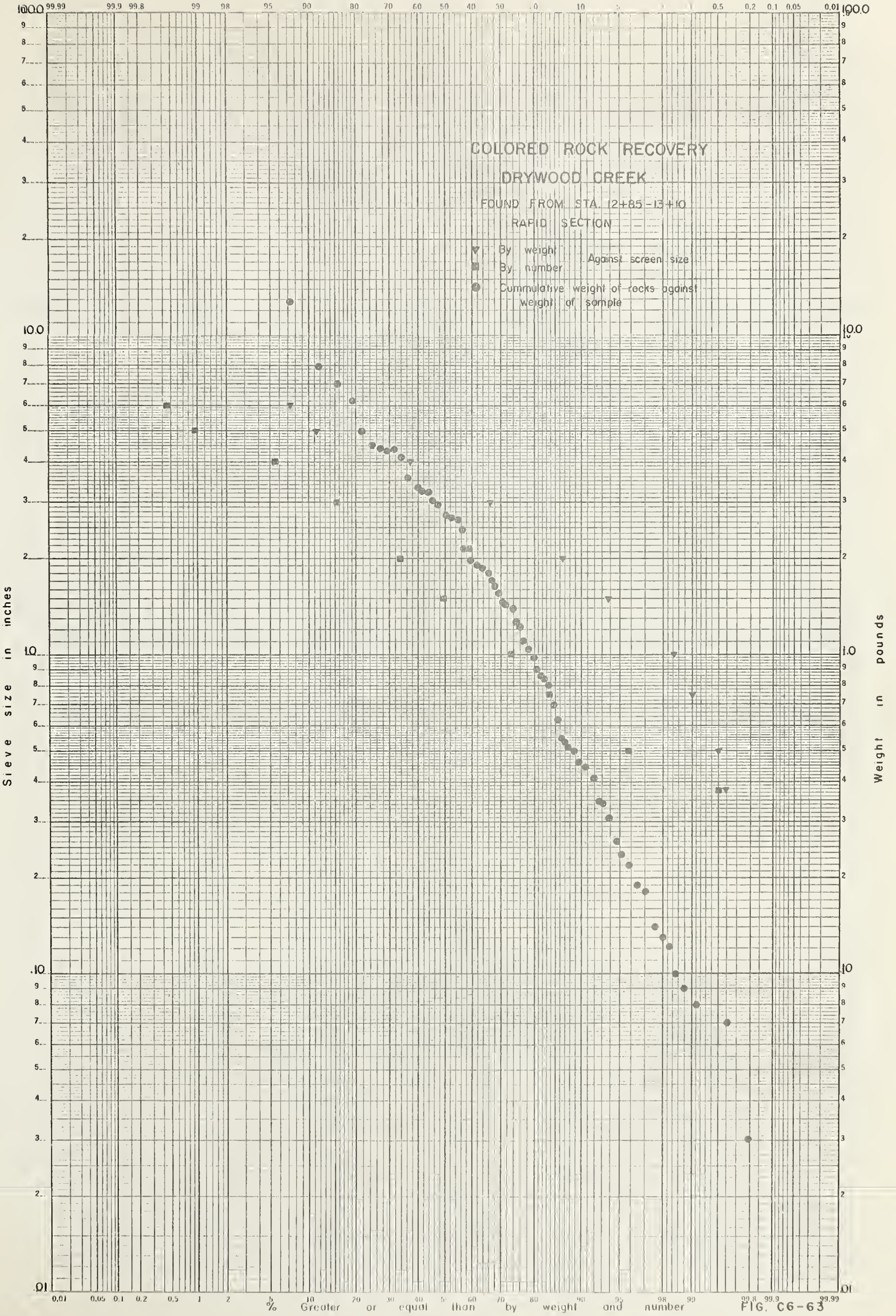

COLORED ROCK RECOVERY
DRYWOOD CREEK
FOUND FROM STA. 12+85 - 13+10
RAPID SECTION
▼ By weight
■ By number
Against screen size
● Cummulative weight of rocks against weight of sample
Sieve size in inches
Weight in pounds
% Greater or equal than by weight and number
100.0
10.0
1.0
.10
.01
99.99
99.9
99.8
99
98
95
90
80
70
60
50
40
30
20
10
5
2
1
0.5
0.2
0.1
0.05
0.01

FIG. C6-63

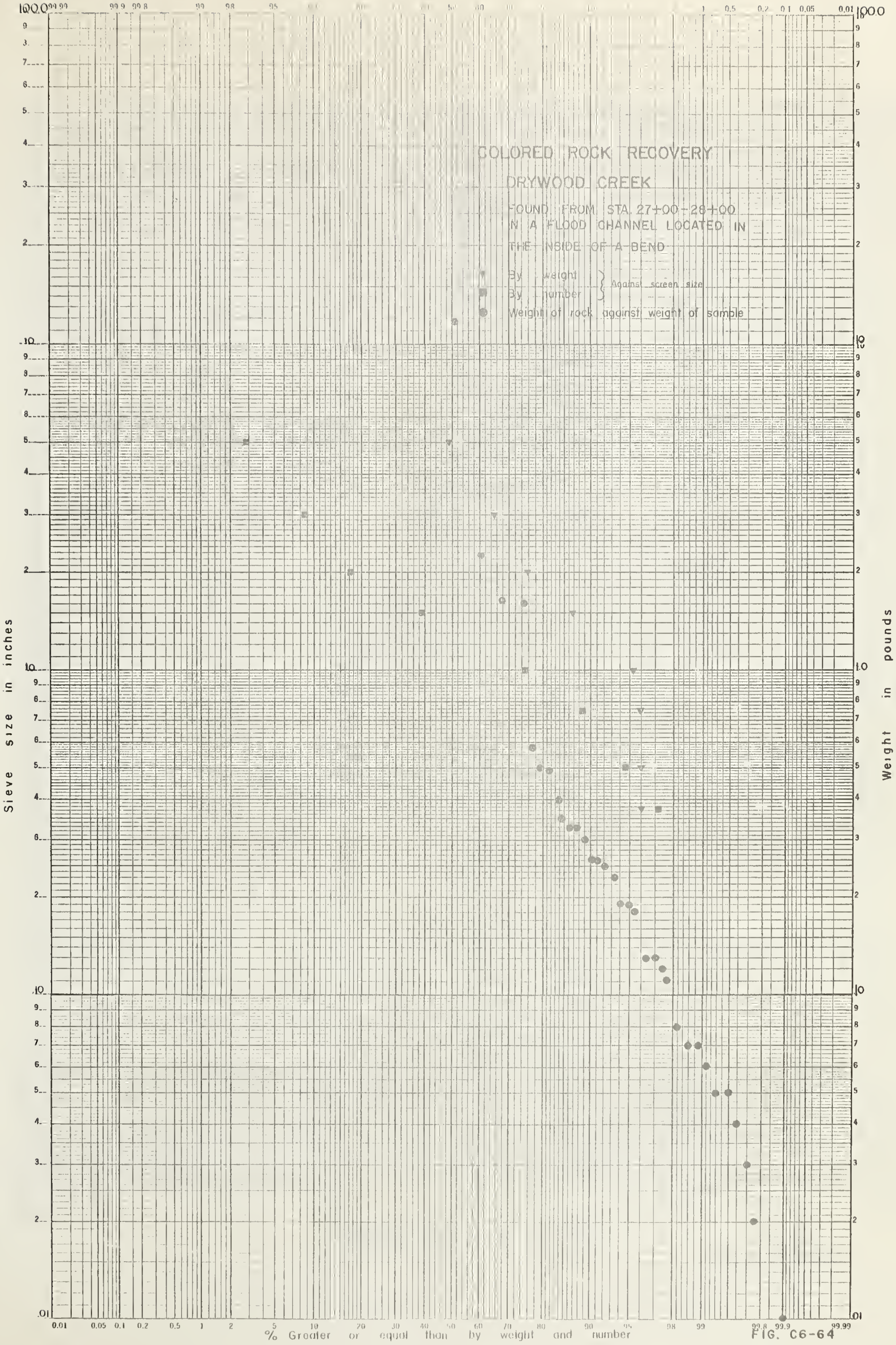

COLORED ROCK RECOVERY
DRYWOOD CREEK
FOUND FROM STA. 27+00 - 28+00
IN A FLOOD CHANNEL LOCATED IN
THE INSIDE OF A BEND
▼ By weight
■ By number
} Against screen size
● Weight of rock against weight of sample
Sieve size in inches
Weight in pounds
% Greater or equal than by weight and number
100.0
10
1.0
.10
.01
0.01
0.05
0.1
0.2
0.5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.8
99.9
99.99

FIG. C6-64

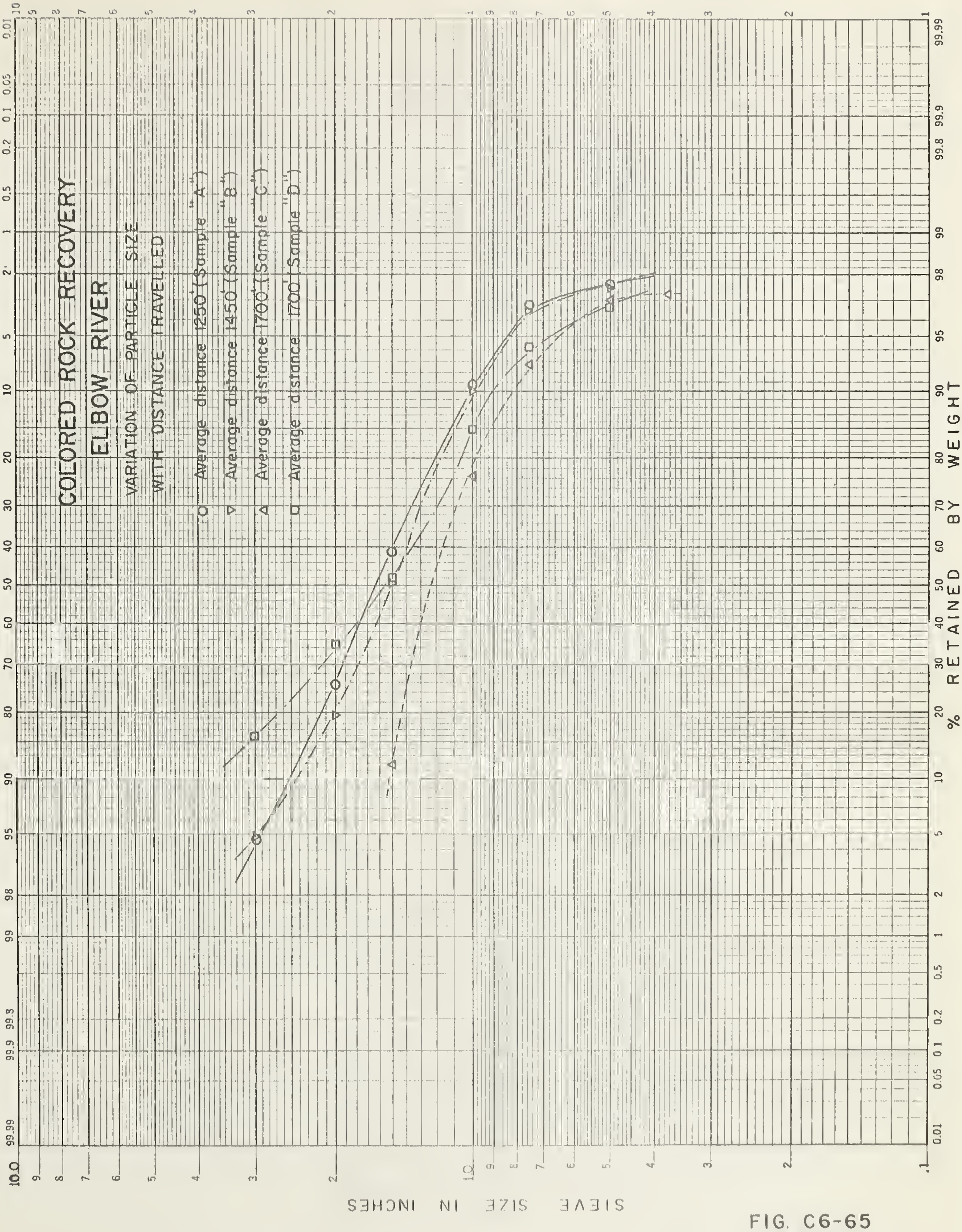

COLORED ROCK RECOVERY
ELBOW RIVER
VARIATION OF PARTICLE SIZE
WITH DISTANCE TRAVELLED
○ Average distance 1250' (Sample "A")
▽ Average distance 1450' (Sample "B")
△ Average distance 1700' (Sample "C")
□ Average distance 1700' (Sample "D")
% RETAINED BY WEIGHT
SIEVE SIZE IN INCHES
10.0
9
8
7
6
5
4
3
2
1.0
.1
0.01
0.05
0.1
0.2
0.5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.8
99.9
99.99

FIG. C6-65

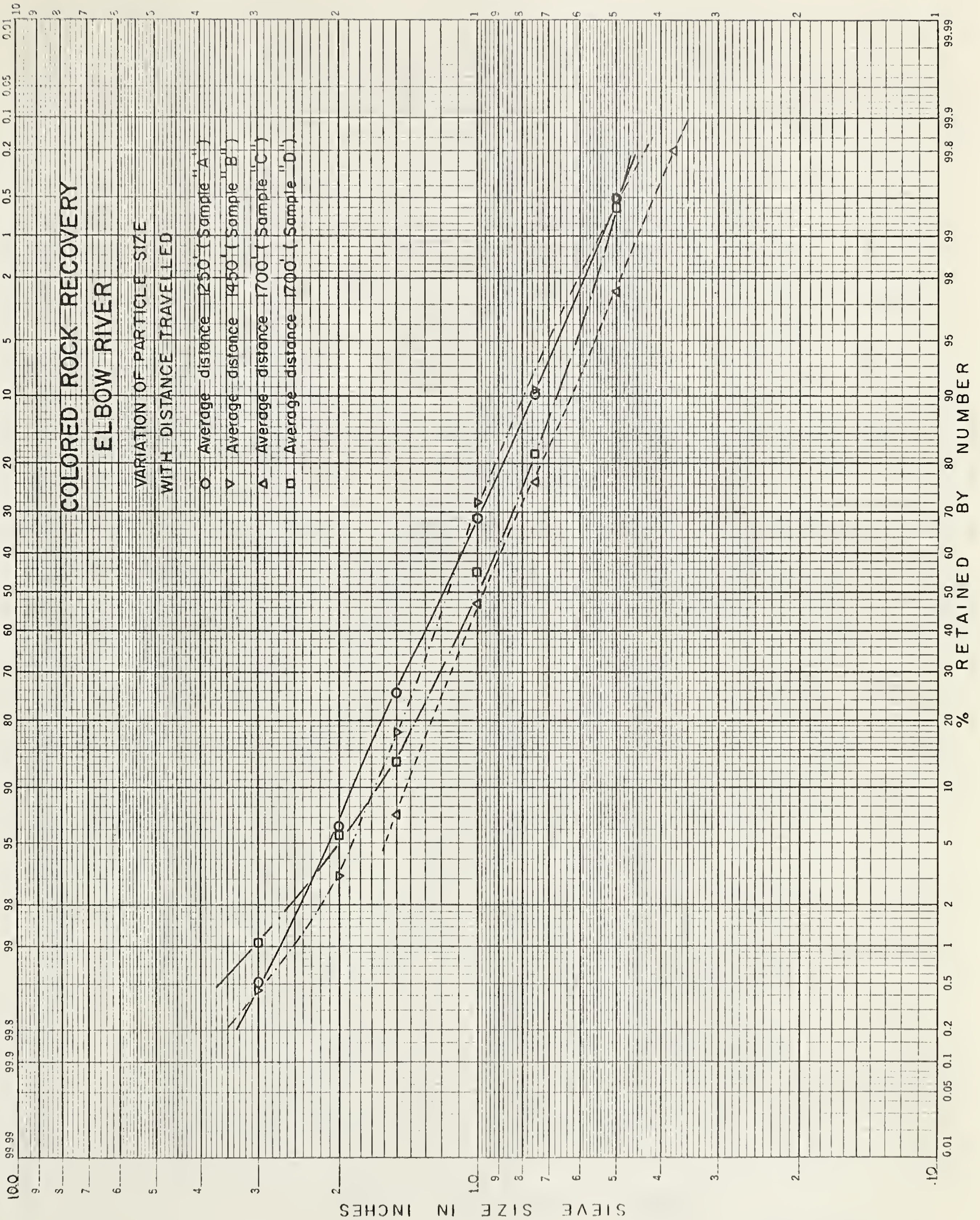

COLORED ROCK RECOVERY
ELBOW RIVER
VARIATION OF PARTICLE SIZE
WITH DISTANCE TRAVELLED
○ Average distance 1250' (Sample "A")
▽ Average distance 1450' (Sample "B")
△ Average distance 1700' (Sample "C")
□ Average distance 1700' (Sample "D")
% RETAINED BY NUMBER
SIEVE SIZE IN INCHES
10.0
1.0
.10
99.99
99.9
99.8
99
98
95
90
80
70
60
50
40
30
20
10
5
2
1
0.5
0.2
0.1
0.05
0.01

FIG. C6-66

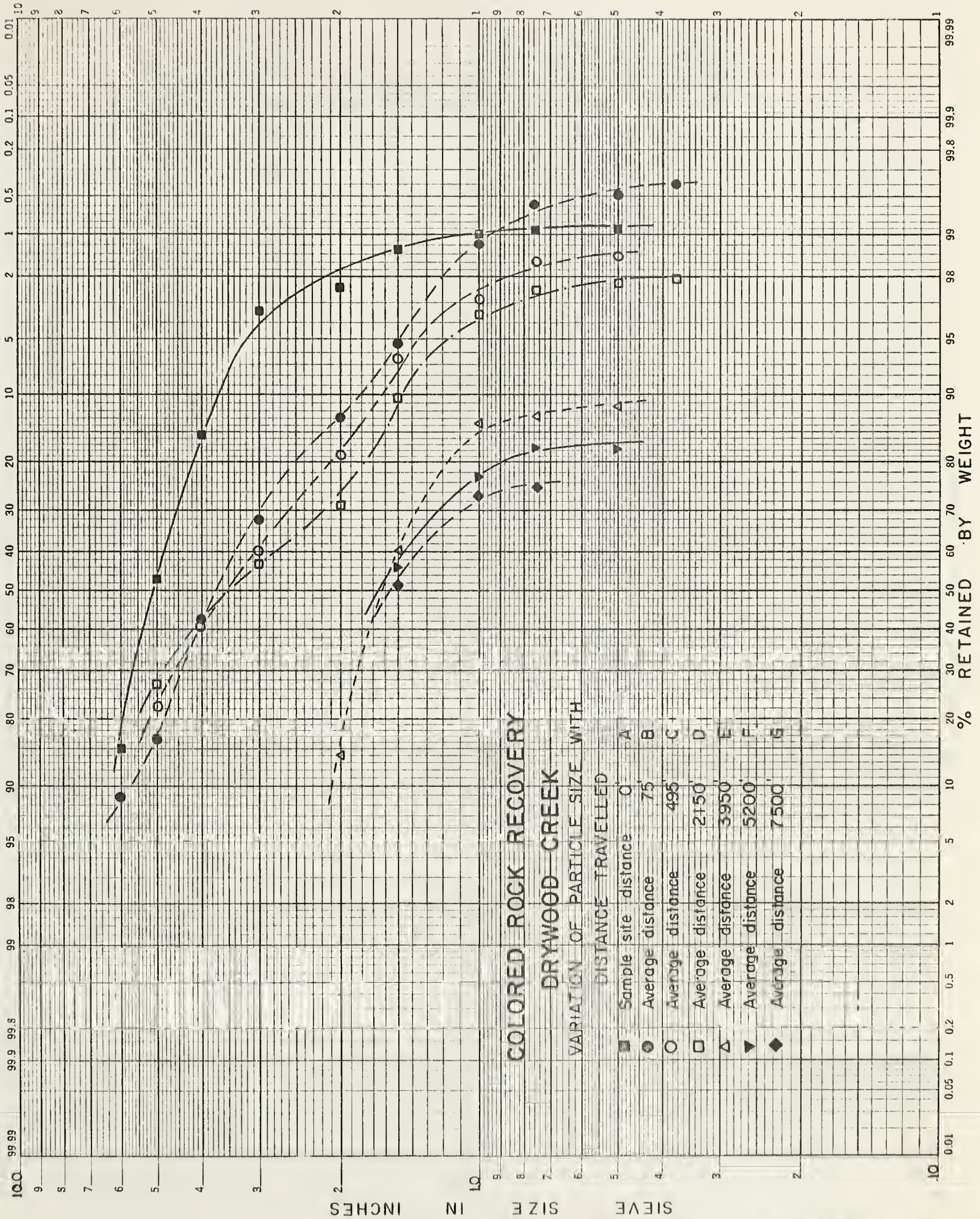

COLORED ROCK RECOVERY
DRYWOOD CREEK
VARIATION OF PARTICLE SIZE WITH DISTANCE TRAVELLED
■ Sample site distance 0' A
● Average distance 75' B
○ Average distance 495' C
□ Average distance 2150' D
△ Average distance 3950' E
▼ Average distance 5200' F
◆ Average distance 7500' G
SIEVE SIZE IN INCHES
% RETAINED BY WEIGHT
10.0
1.0
.10
99.99
99.9
99.8
99
98
95
90
80
70
60
50
40
30
20
10
5
2
1
0.5
0.2
0.1
0.05
0.01

FIG. C6-67

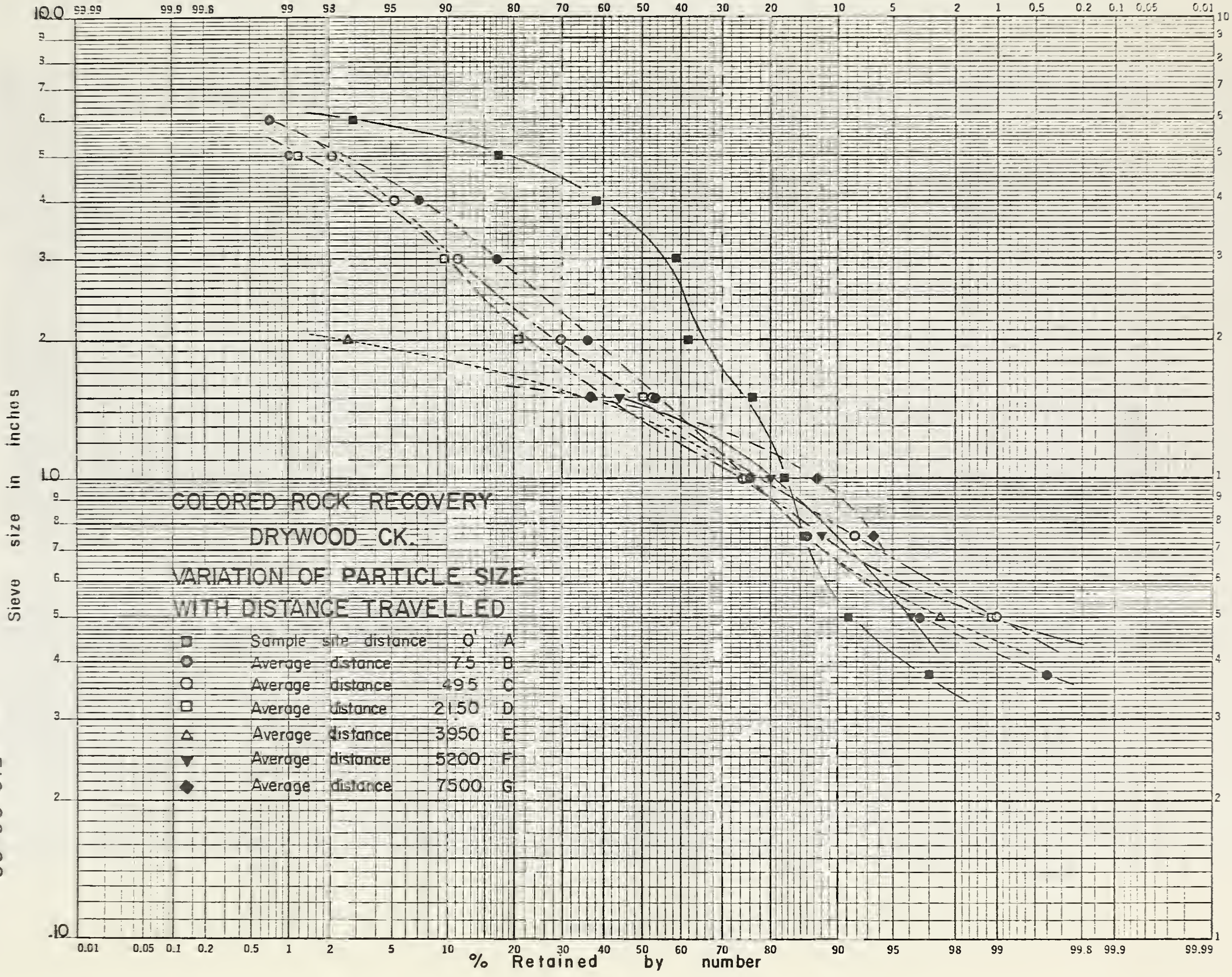

COLORED ROCK RECOVERY
DRYWOOD CK.
VARIATION OF PARTICLE SIZE
WITH DISTANCE TRAVELLED
■ Sample site distance 0' A
◉ Average distance 75 B
○ Average distance 495 C
□ Average distance 2150 D
△ Average distance 3950 E
▼ Average distance 5200 F
◆ Average distance 7500 G
Sieve size in inches
% Retained by number
10.0
1.0
.10
9
8
7
6
5
4
3
2
0.01
0.05
0.1
0.2
0.5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.8
99.9
99.99

FIG. C6-68

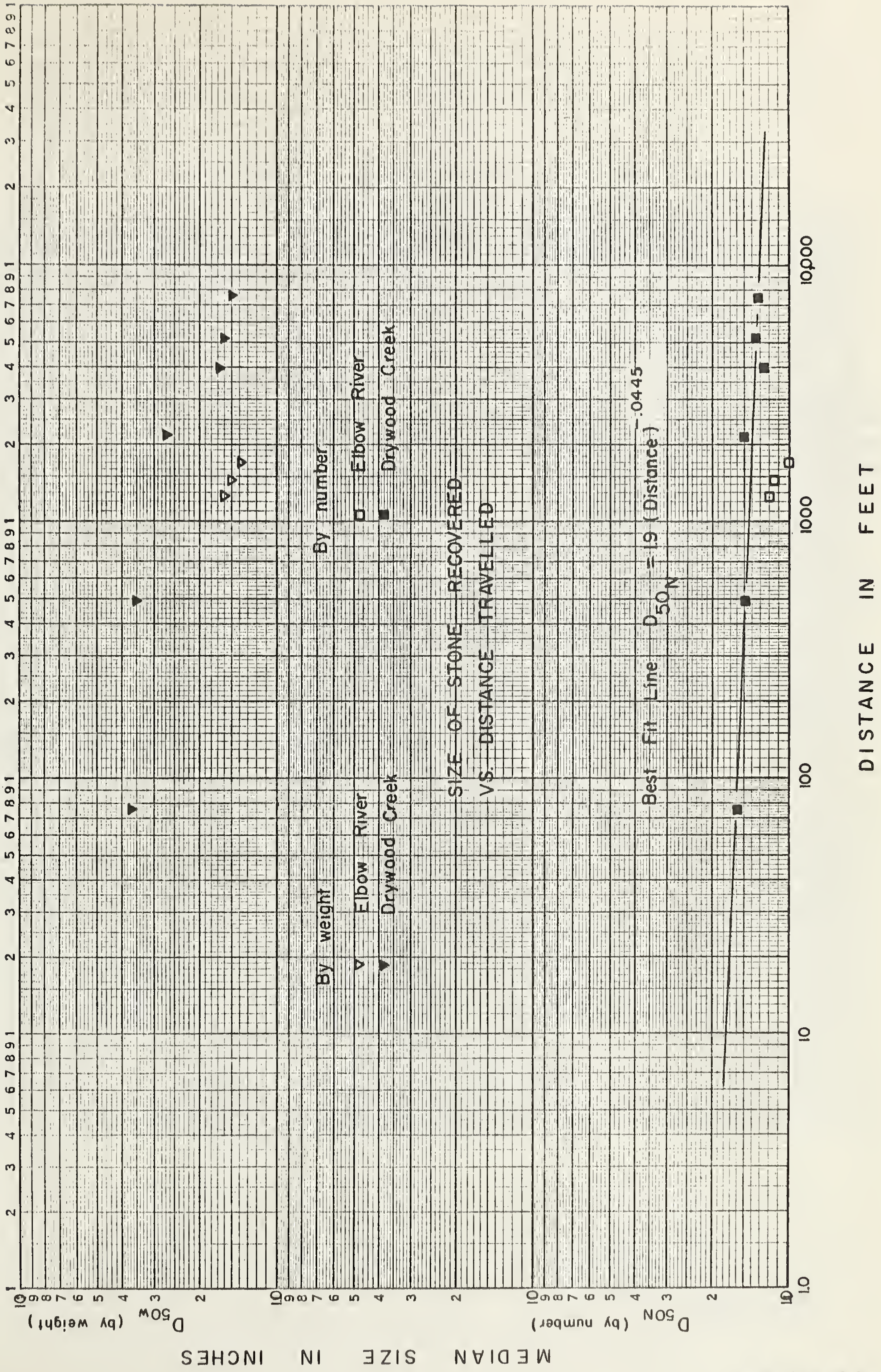

SIZE OF STONE RECOVERED
VS. DISTANCE TRAVELLED
By weight
Elbow River
Drywood Creek
By number
Elbow River
Drywood Creek
Best Fit Line $D_{50_N} = 1.9\,(\text{Distance})^{-.0445}$
DISTANCE IN FEET
1.0
10
100
1000
10,000
MEDIAN SIZE IN INCHES
D_{50W} (by weight)
D_{50N} (by number)
1
2
3
4
5
6
7
8
9
10

FIG. C6-69

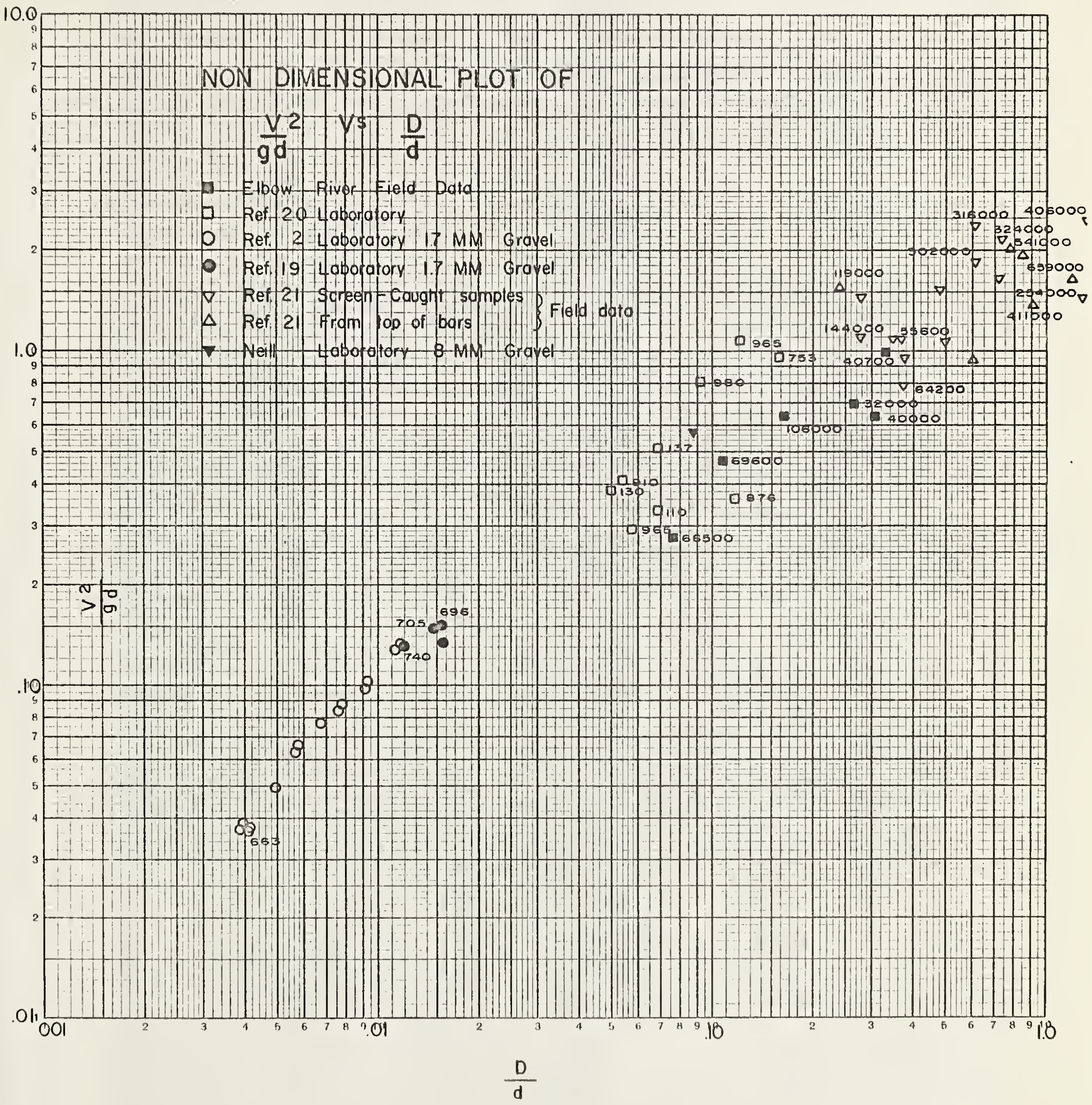

NON DIMENSIONAL PLOT OF
$\frac{V^2}{gd}$ Vs $\frac{D}{d}$
■ Elbow River Field Data
□ Ref. 20 Laboratory
○ Ref. 2 Laboratory 1.7 MM Gravel
● Ref. 19 Laboratory 1.7 MM Gravel
▽ Ref. 21 Screen-Caught samples
△ Ref. 21 From top of bars
Field data
▼ Neill Laboratory 8 MM Gravel
10.0
1.0
.10
.01
.001
.01
.10
1.0
$\frac{V^2}{gd}$
$\frac{D}{d}$
663
705
696
740
965
753
980
137
69600
510
130
876
110
965
66500
106000
32000
40000
64200
40700
144000
55600
119000
302000
316000
324000
406000
541000
659000
254000
411000

FIG. C6-70

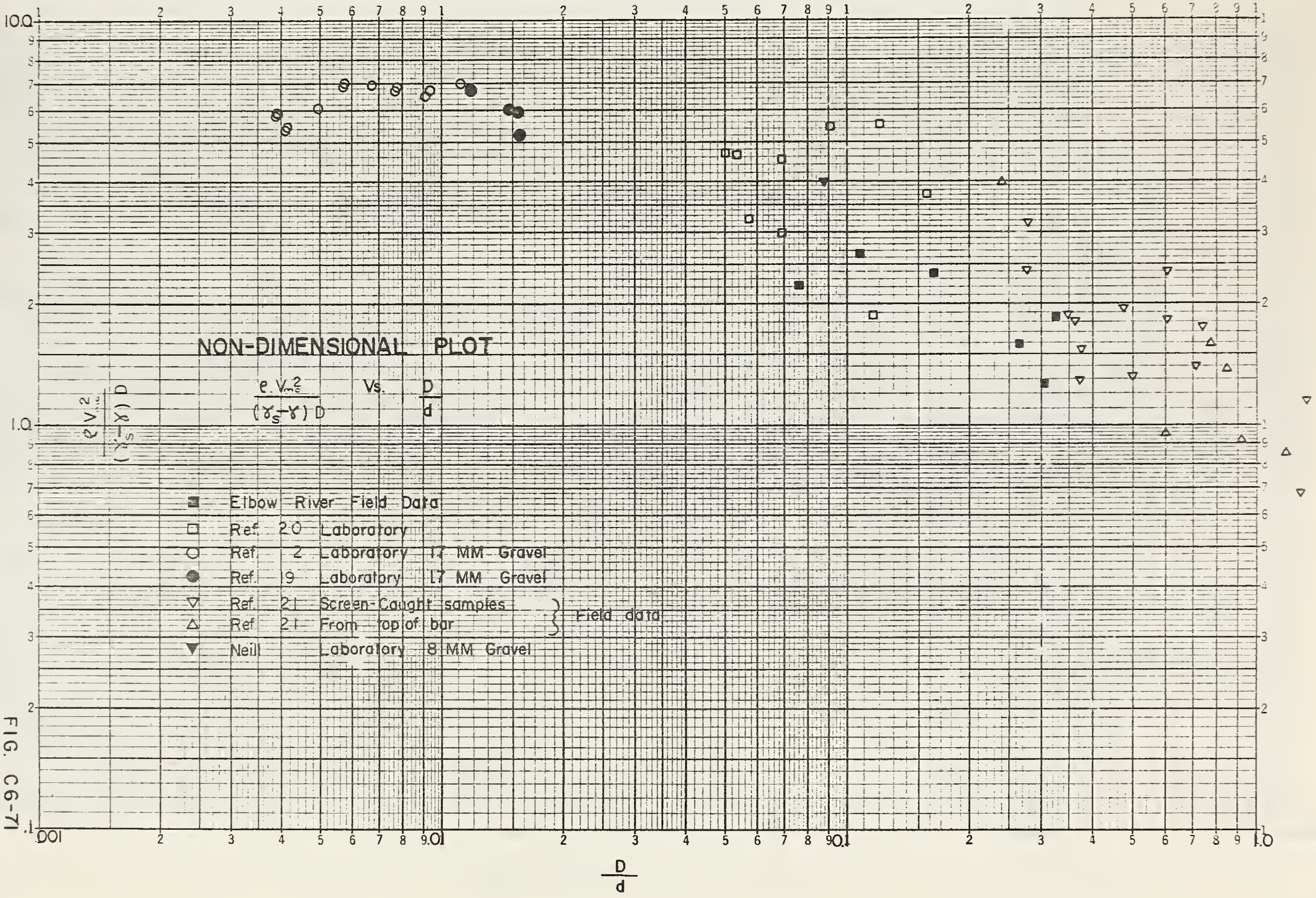

NON-DIMENSIONAL PLOT
$\frac{\rho V_{mc}^2}{(\gamma_s - \gamma) D}$ Vs. $\frac{D}{d}$
$\frac{\rho V_{mc}^2}{(\gamma_s - \gamma) D}$
$\frac{D}{d}$
10.0
1.0
.1
.001
.01
0.1
1.0
■ Elbow River Field Data
□ Ref. 20 Laboratory
○ Ref. 2 Laboratory 17 MM Gravel
● Ref. 19 Laboratory 17 MM Gravel
▽ Ref. 21 Screen-Caught samples
△ Ref. 21 From top of bar
Field data
▼ Neill Laboratory 8 MM Gravel

FIG. C6-71

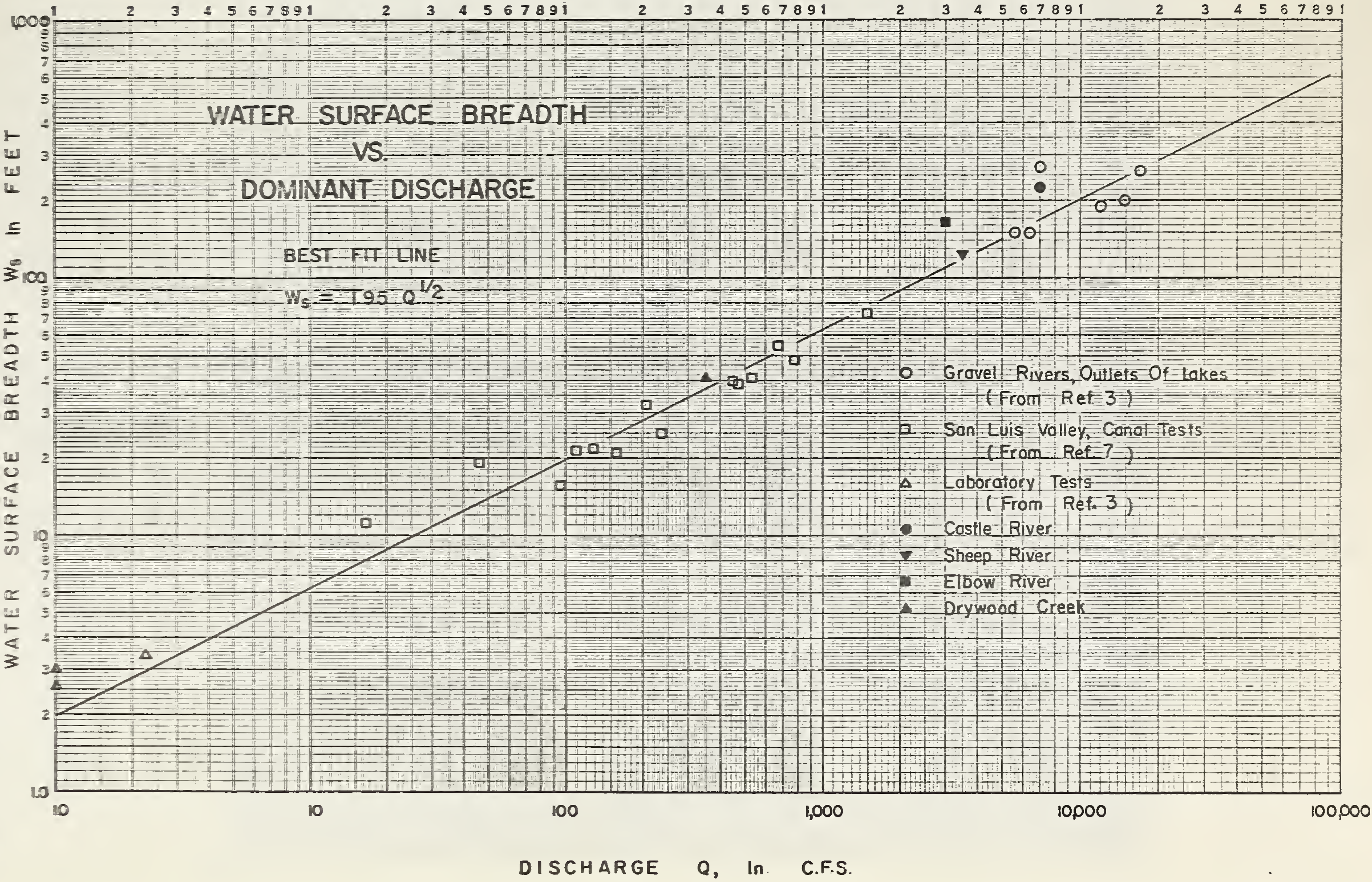

WATER SURFACE BREADTH
VS.
DOMINANT DISCHARGE
BEST FIT LINE
$W_s = 1.95\ Q^{1/2}$
○ Gravel Rivers, Outlets Of Lakes (From Ref. 3)
□ San Luis Valley, Canal Tests (From Ref. 7)
△ Laboratory Tests (From Ref. 3)
● Castle River
▼ Sheep River
■ Elbow River
▲ Drywood Creek
WATER SURFACE BREADTH W_s In FEET
DISCHARGE Q, In. C.F.S.
1.0
10
100
1,000
10,000
100,000
1.0
10
100
1000

FIG. C7-72

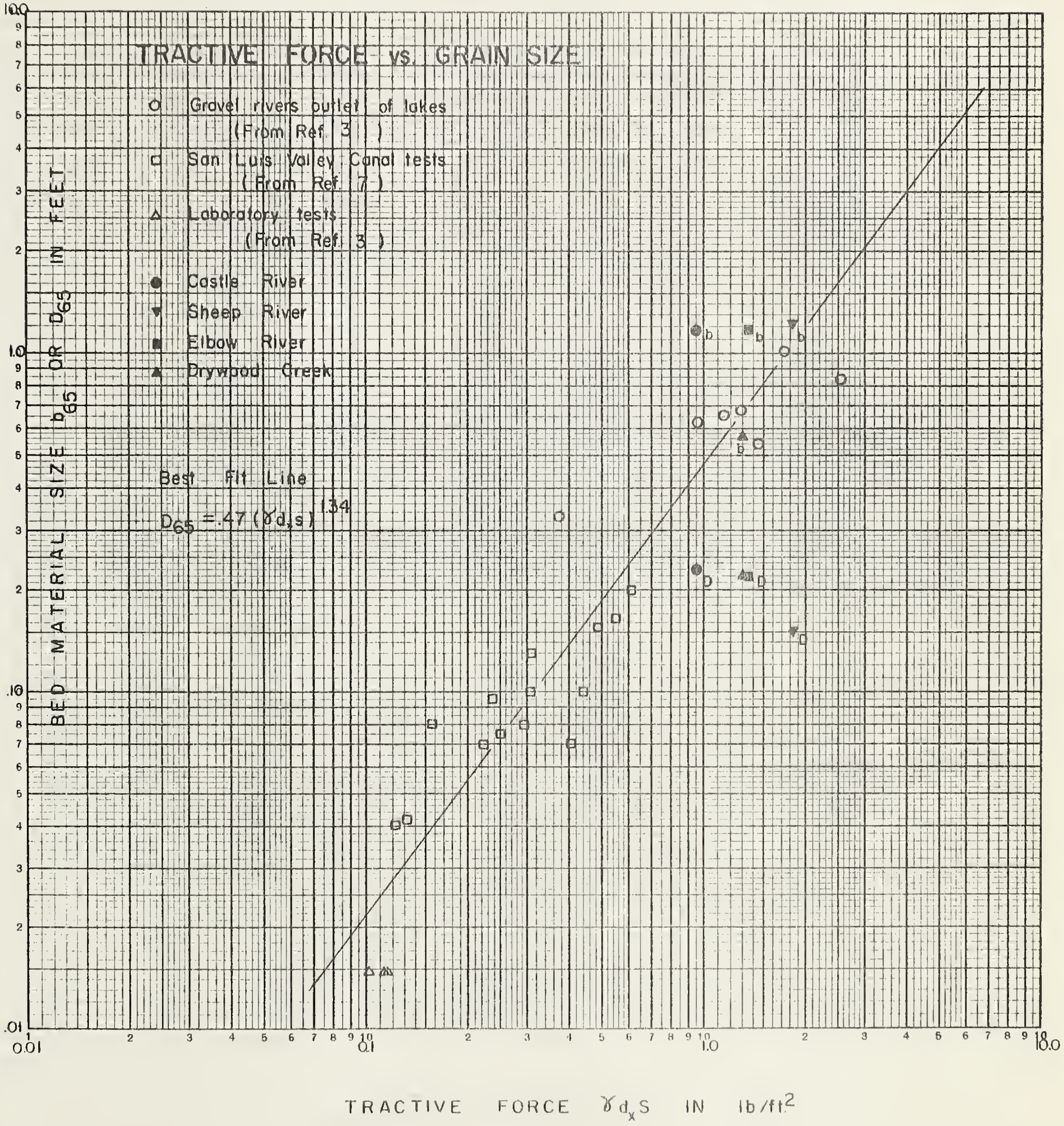

TRACTIVE FORCE vs. GRAIN SIZE
○ Gravel rivers outlet of lakes (From Ref. 3)
□ San Luis Valley Canal tests (From Ref. 7)
△ Laboratory tests (From Ref. 3)
● Castle River
▼ Sheep River
■ Elbow River
▲ Drywood Creek
Best Fit Line
$D_{65} = .47(\gamma d_x s)^{1.34}$
b
D
BED MATERIAL SIZE b_{65} OR D_{65} IN FEET
TRACTIVE FORCE $\gamma d_x S$ IN lb/ft.^{2}
10.0
1.0
.10
.01
0.01
0.1
1.0
10.0

FIG. C7-73

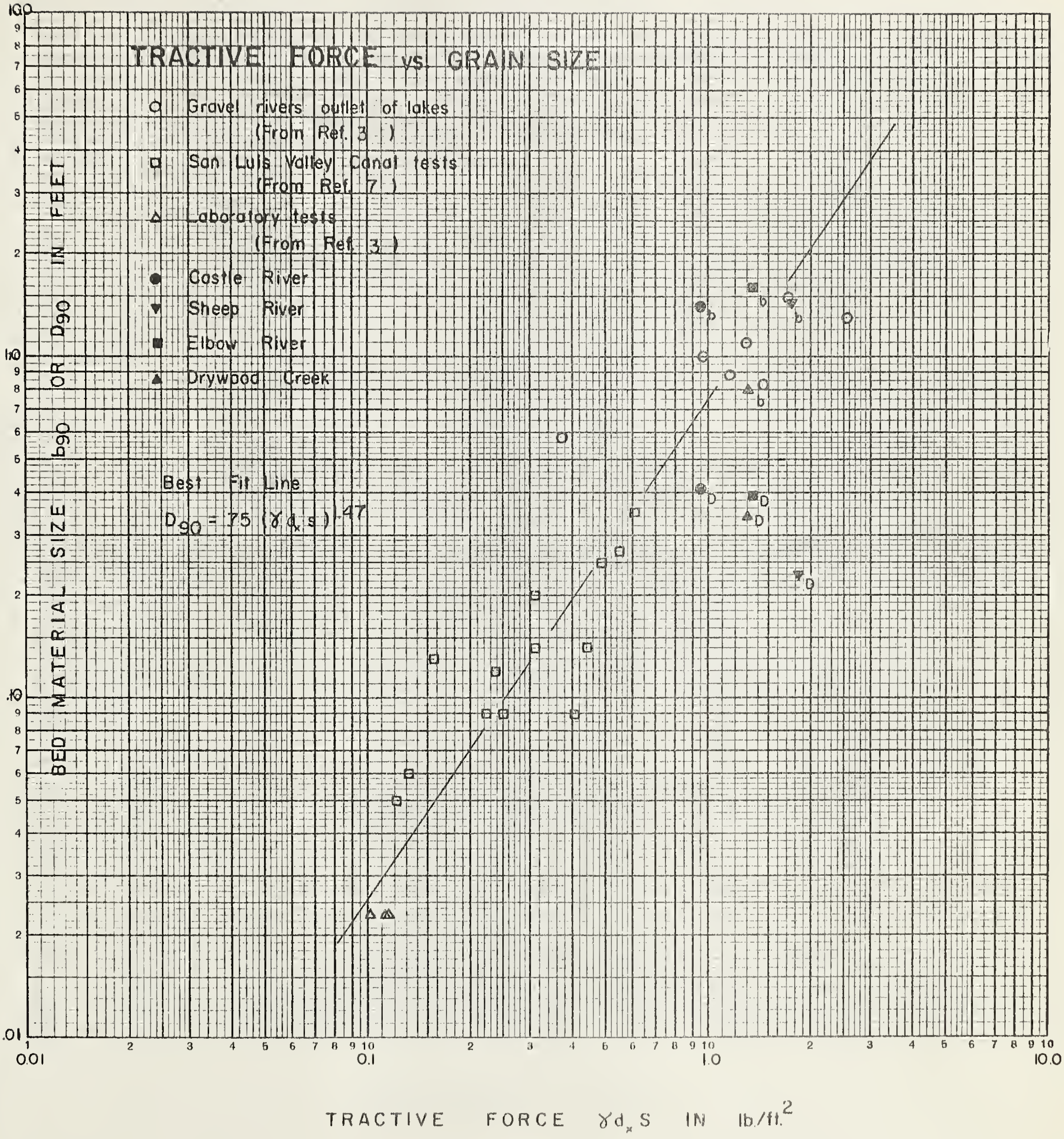

TRACTIVE FORCE vs. GRAIN SIZE
○ Gravel rivers outlet of lakes (From Ref. 3)
□ San Luis Valley Canal tests (From Ref. 7)
△ Laboratory tests (From Ref. 3)
● Castle River
▼ Sheep River
■ Elbow River
▲ Drywood Creek
Best Fit Line
D90 = .75 (γ dx s) .47
BED MATERIAL SIZE D90 OR D90 IN FEET
TRACTIVE FORCE γdx S IN lb/ft.2
100
10
1.0
.10
.01
0.01
0.1
1.0
10.0
b
D

FIG. C7-74

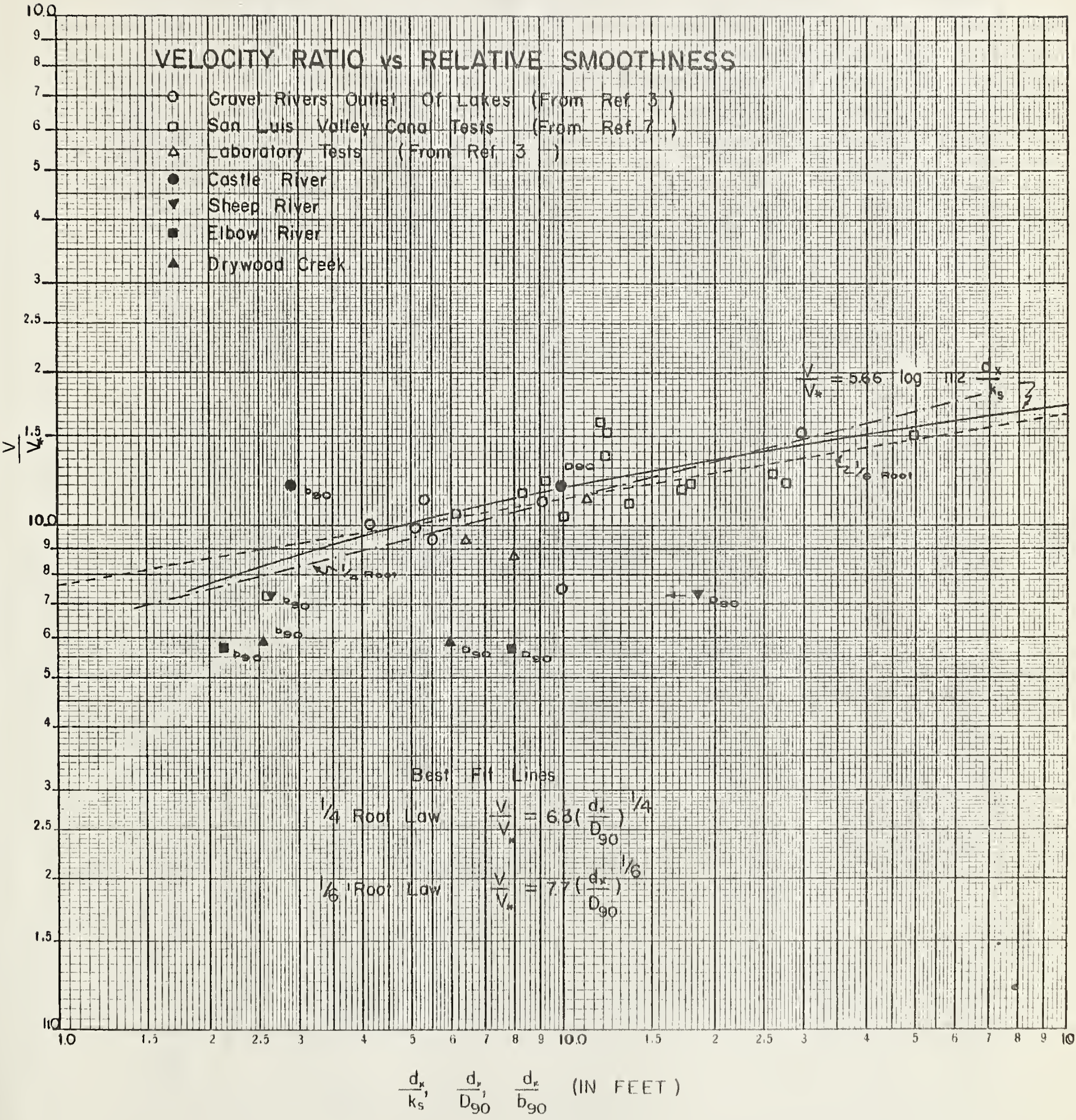

VELOCITY RATIO vs RELATIVE SMOOTHNESS
○ Gravel Rivers Outlet Of Lakes (From Ref 3)
□ San Luis Valley Canal Tests (From Ref 7)
△ Laboratory Tests (From Ref 3)
● Castle River
▼ Sheep River
■ Elbow River
▲ Drywood Creek
$\frac{V}{V_*} = 5.66 \log 11.2 \frac{d_x}{k_s}$
1/4 Root
1/6 Root
b90
D90
Best Fit Lines
1/4 Root Law $\frac{V}{V_*} = 6.8\left(\frac{d_x}{D_{90}}\right)^{1/4}$
1/6 Root Law $\frac{V}{V_*} = 7.7\left(\frac{d_x}{D_{90}}\right)^{1/6}$
$\frac{V}{V_*}$
10.0
9
8
7
6
5
4
3
2.5
2
1.5
1.0
1.0
1.5
2
2.5
3
4
5
6
7
8
9
10.0
1.5
2
2.5
3
4
5
6
7
8
9
100
$\frac{d_x}{k_s}$, $\frac{d_x}{D_{90}}$, $\frac{d_x}{b_{90}}$ (IN FEET)

FIG. C7-75

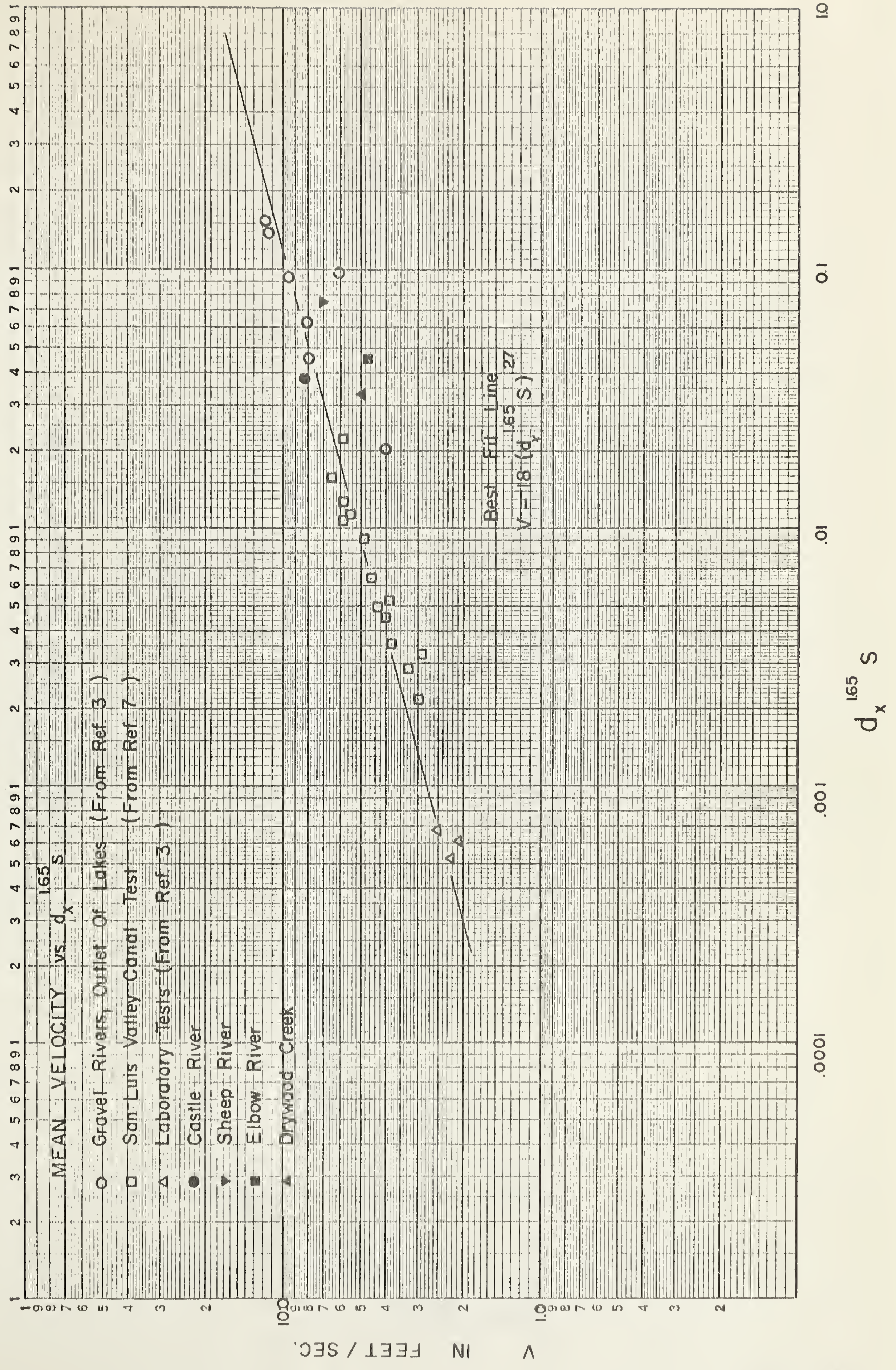

MEAN VELOCITY vs. $d_x^{1.65}$ S
○ Gravel Rivers, Outlet Of Lakes (From Ref. 3)
□ San Luis Valley Canal Test (From Ref. 7)
△ Laboratory Tests (From Ref. 3)
● Castle River
▼ Sheep River
■ Elbow River
▲ Drywood Creek
Best Fit Line
$V = 18 (d_x^{1.65} S)^{.27}$
$d_x^{1.65}$ S
V IN FEET / SEC.
.0001
.001
.01
0.1
1.0
10
1.0

FIG. C7-76

REGIME SLOPE ANALYSIS CHART
(MOBILE-BED FLUVIOLOGY — BLENCH)

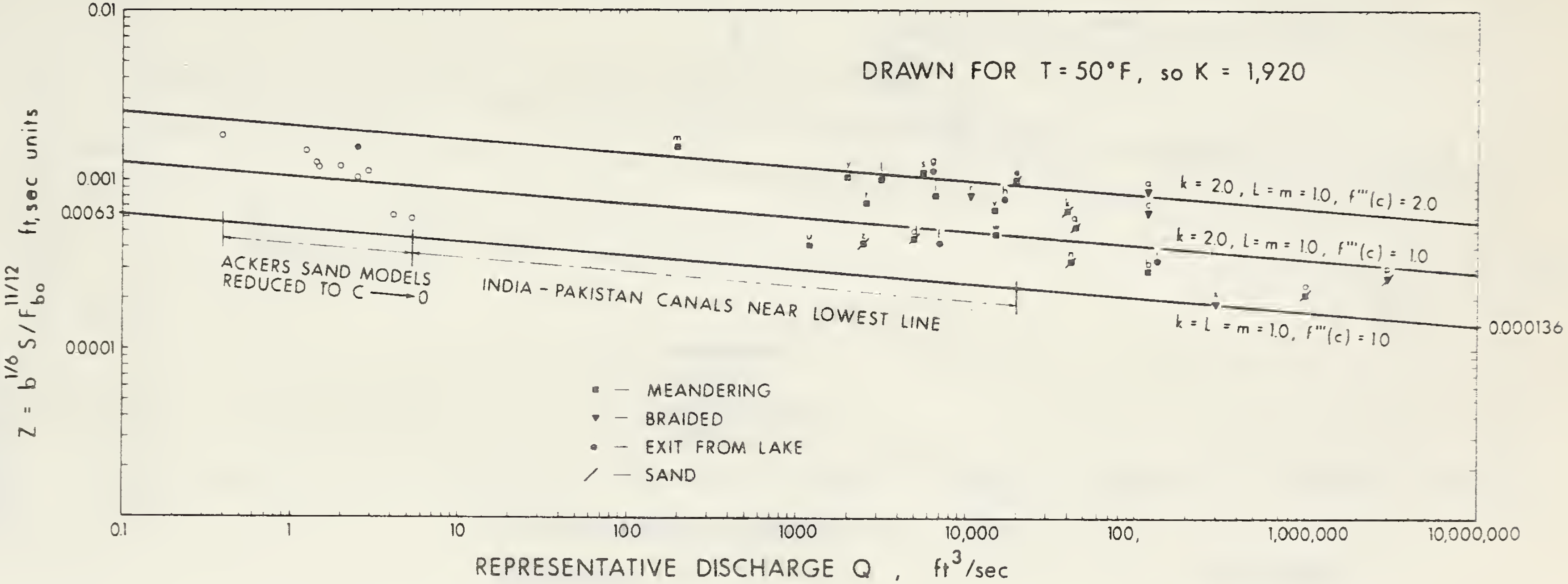


FIG. C7-77

REGIME SLOPE ANALYSIS CHART

(MOBILE-BED FLUVIOLOGY — BLENCH)

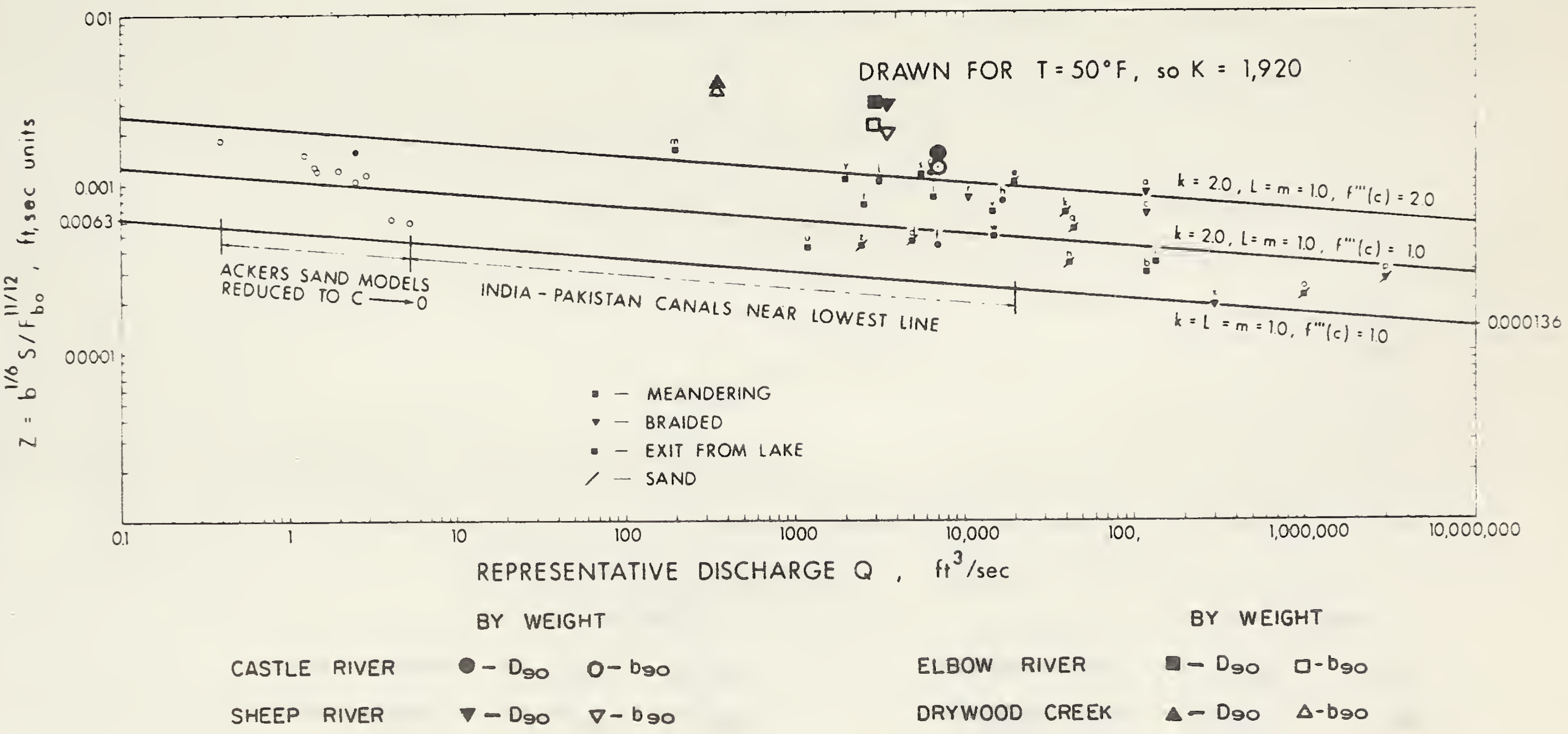


FIG. C7-78

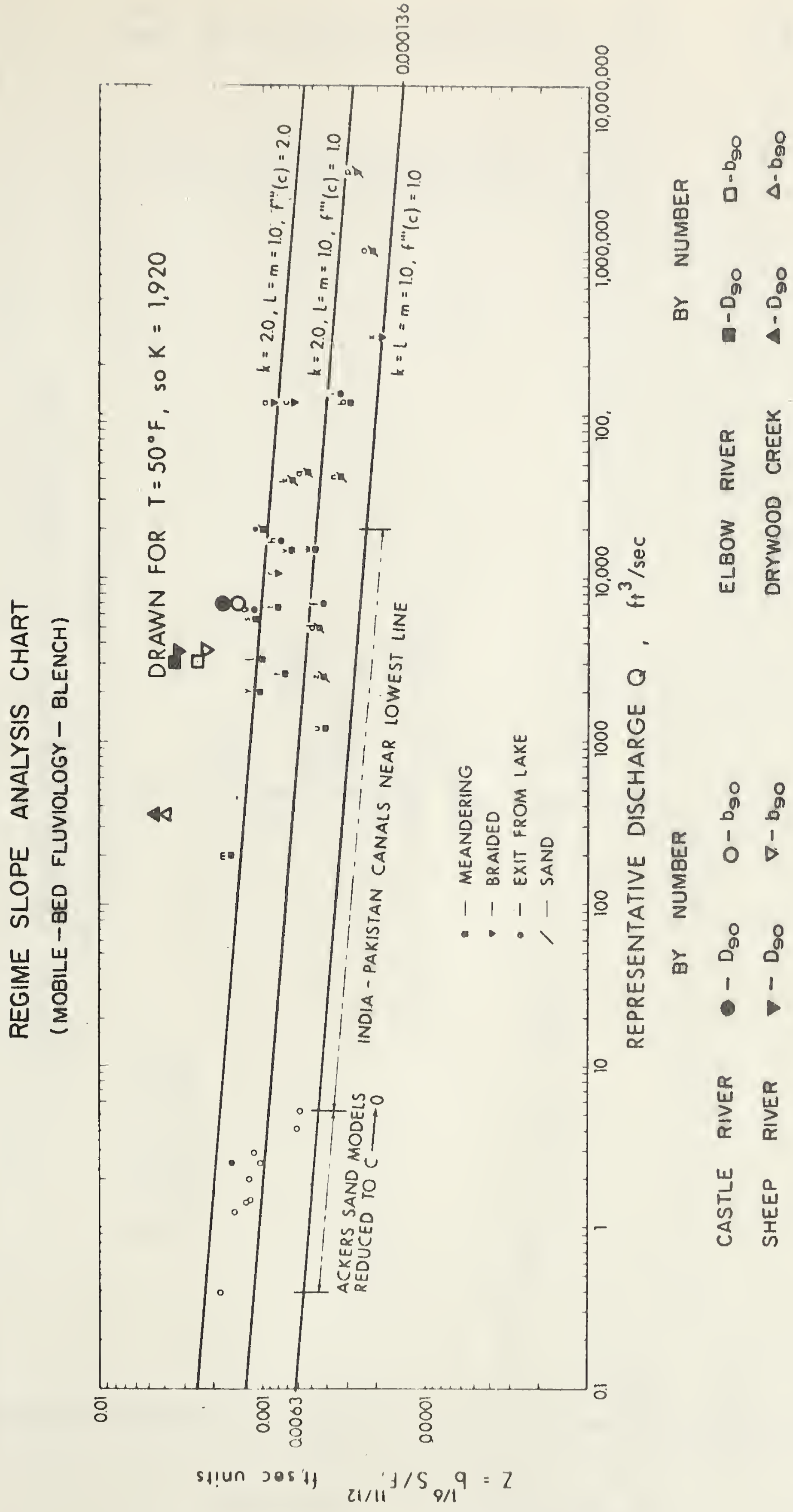

REGIME SLOPE ANALYSIS CHART
(MOBILE-BED FLUVIOLOGY - BLENCH)
DRAWN FOR T = 50°F, so K = 1,920
k = 2.0, L = m = 1.0, f'''(c) = 2.0
k = 2.0, L = m = 1.0, f'''(c) = 1.0
k = L = m = 1.0, f'''(c) = 1.0
0.000136
INDIA - PAKISTAN CANALS NEAR LOWEST LINE
ACKERS SAND MODELS REDUCED TO C → 0
■ — MEANDERING
▼ — BRAIDED
● — EXIT FROM LAKE
/ — SAND
0.01
0.001
0.0063
0.0001
Z = b 1/6 S/F 11/12 ft, sec units
0.1
1
10
100
1000
10,000
100,000
1,000,000
10,000,000
REPRESENTATIVE DISCHARGE Q , ft³/sec
BY NUMBER
CASTLE RIVER ● - D90 ○ - b90
SHEEP RIVER ▼ - D90 ▽ - b90
BY NUMBER
ELBOW RIVER ■ - D90 □ - b90
DRYWOOD CREEK ▲ - D90 △ - b90

FIG. C7-79

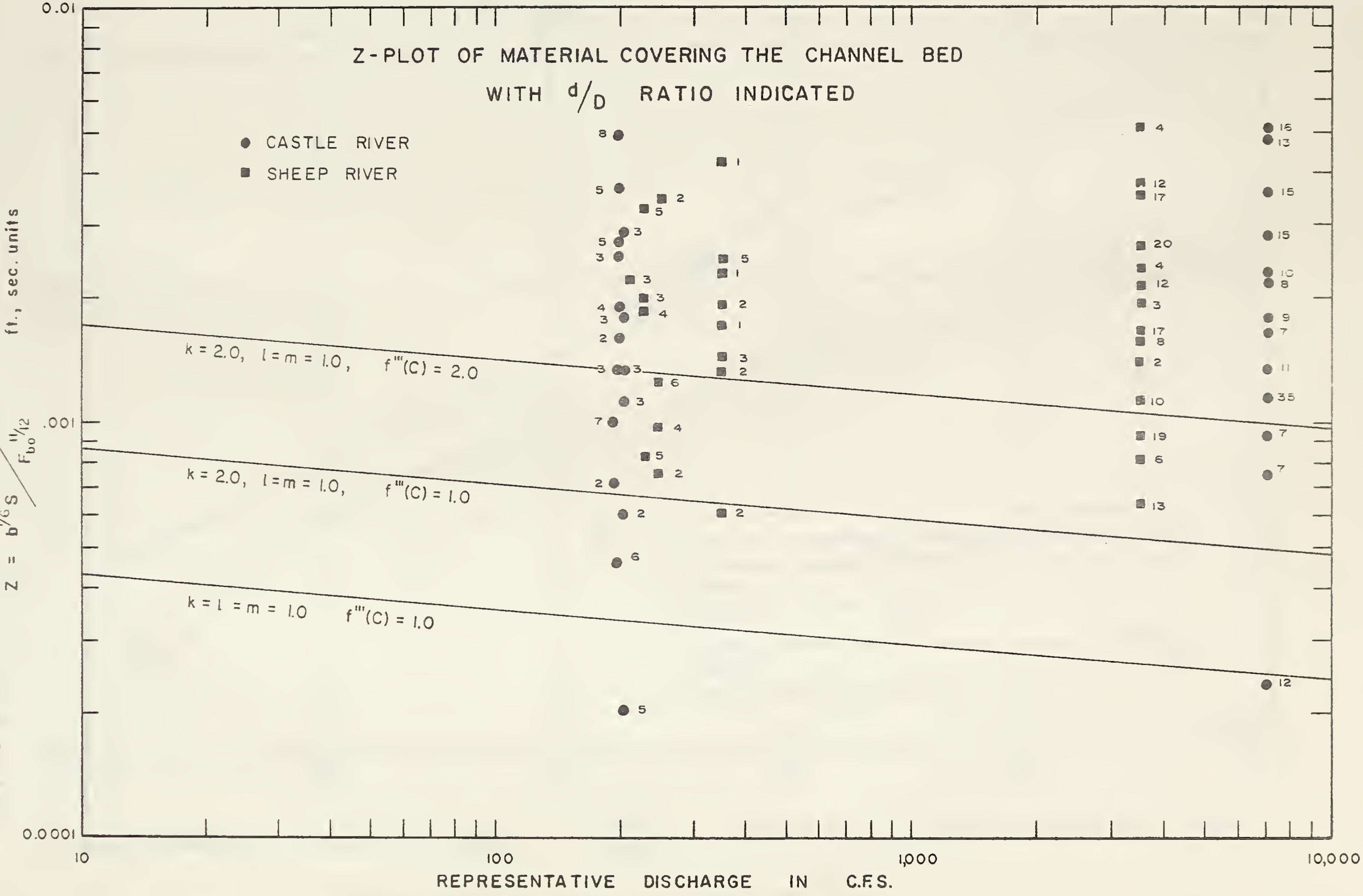
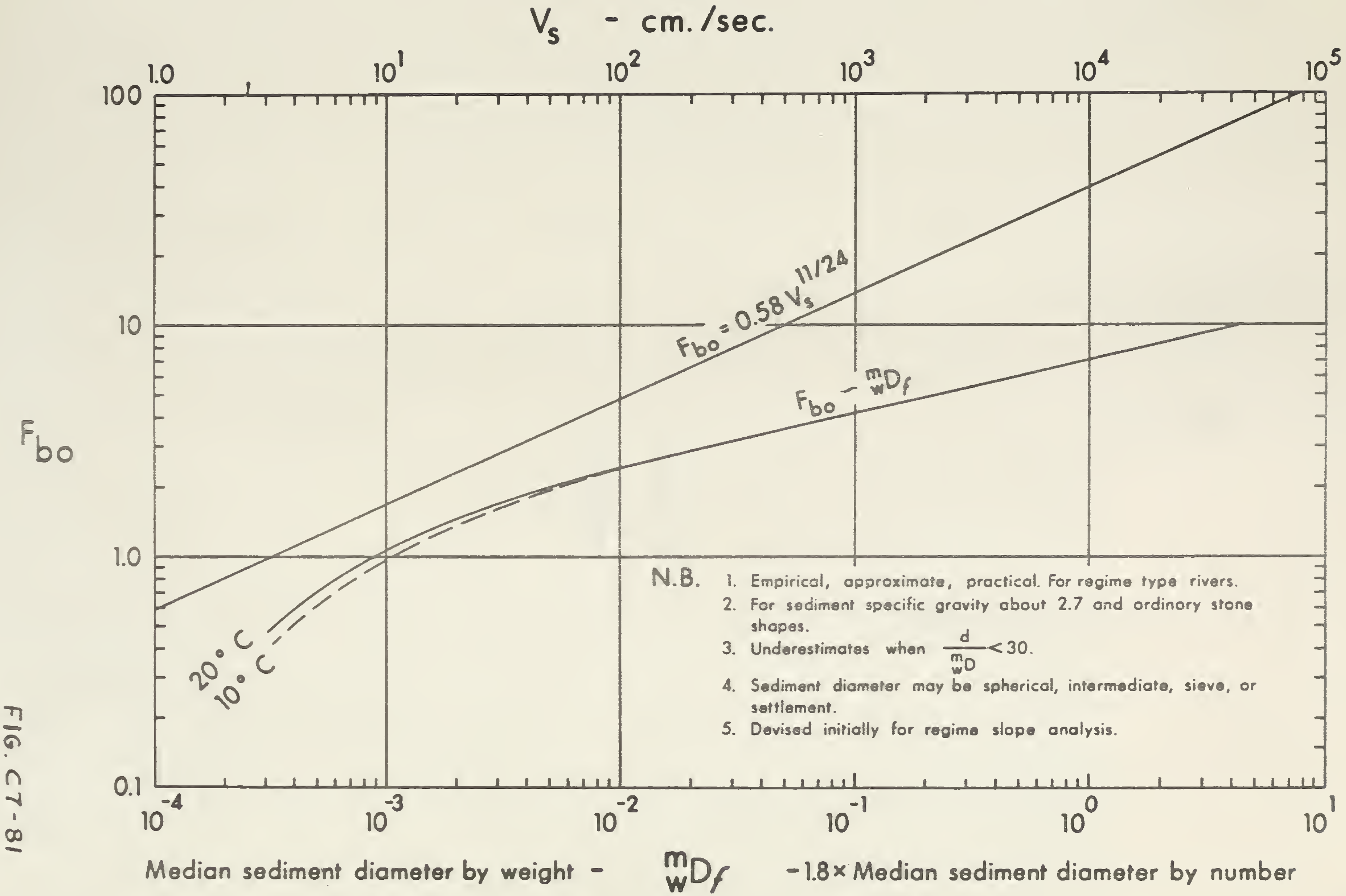

Z-PLOT OF MATERIAL COVERING THE CHANNEL BED
WITH d/D RATIO INDICATED
● CASTLE RIVER
■ SHEEP RIVER
k = 2.0, l = m = 1.0, f'''(C) = 2.0
k = 2.0, l = m = 1.0, f'''(C) = 1.0
k = l = m = 1.0 f'''(C) = 1.0
0.01
.001
0.0001
10
100
1,000
10,000
Z = b^1/6 S / F_bo^11/12 ft., sec. units
REPRESENTATIVE DISCHARGE IN C.F.S.
8
5
3
5
3
4
3
2
3
3
3
7
2
2
6
5
2
5
3
3
4
6
4
5
2
1
5
1
2
1
3
2
2
4
12
17
20
4
12
3
17
8
2
10
19
6
13
16
13
15
15
10
8
9
7
11
35
7
7
12

FIG. C7-80



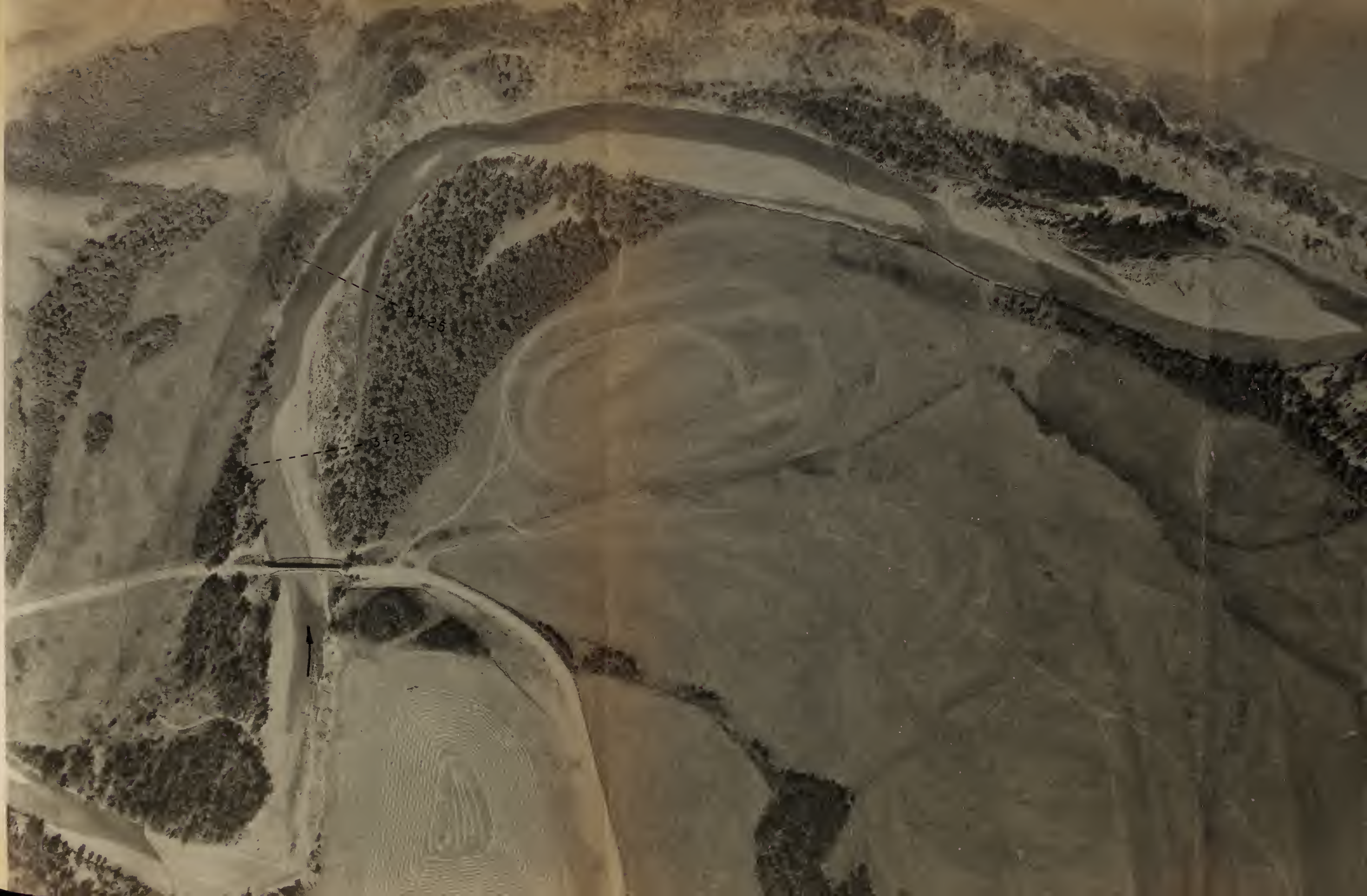
N.B.
1. Empirical, approximate, practical. For regime type rivers.
2. For sediment specific gravity about 2.7 and ordinary stone shapes.
3. Underestimates when $\frac{d}{{}^m_wD} < 30$.
4. Sediment diameter may be spherical, intermediate, sieve, or settlement.
5. Devised initially for regime slope analysis.

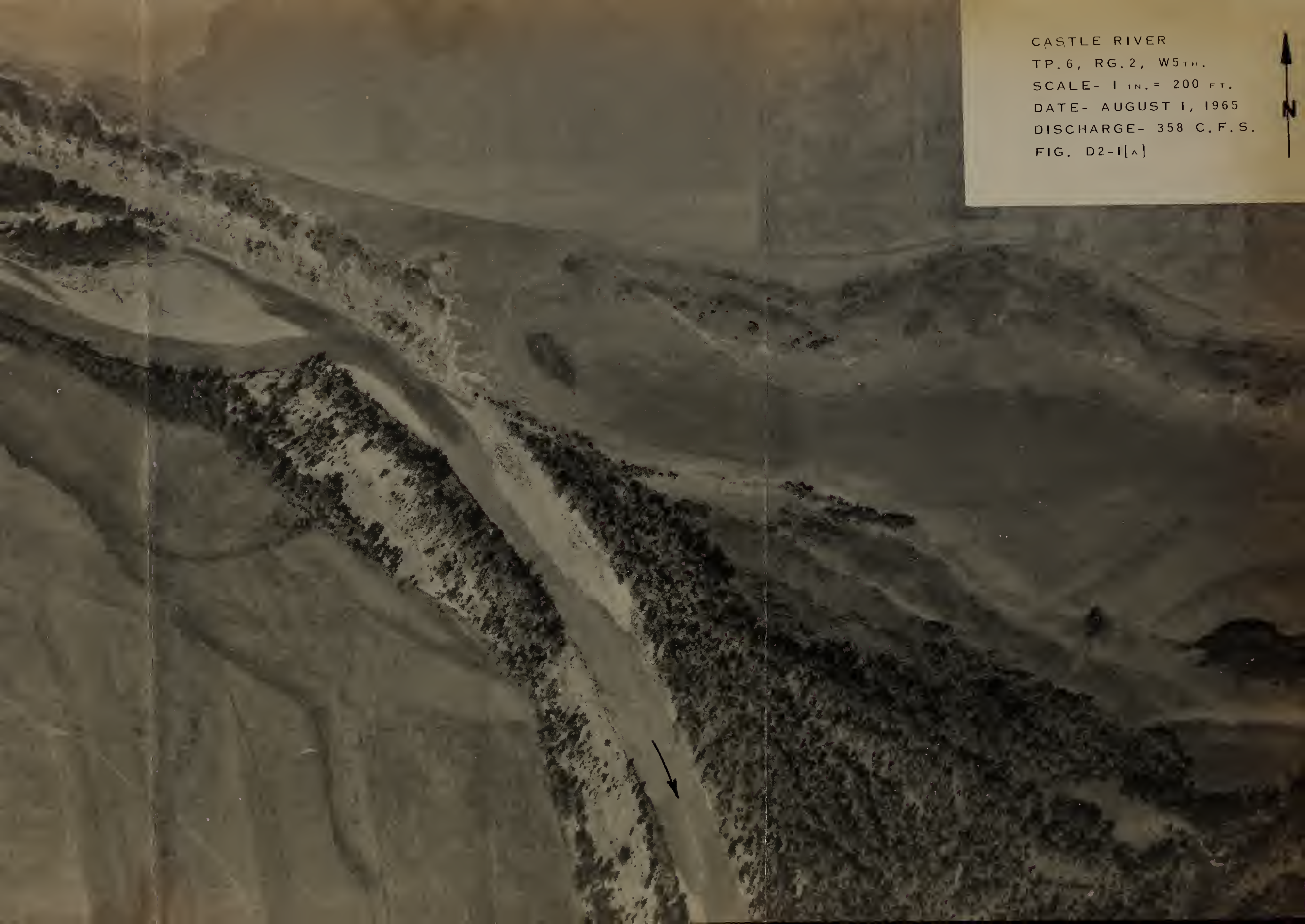
Tentative chart for practical estimation of F_{bo}.

FIG. C7-81

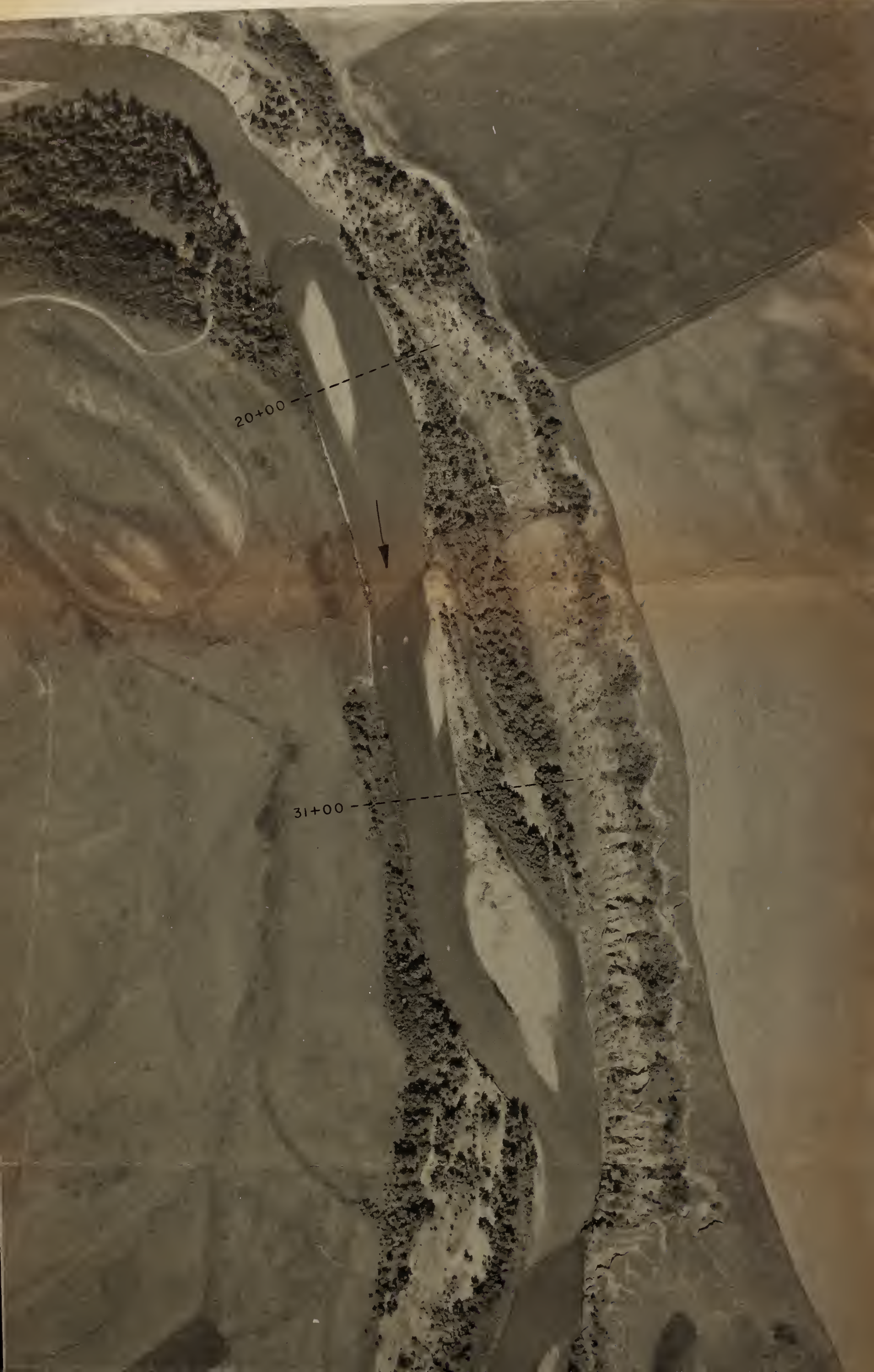
APPENDIX D

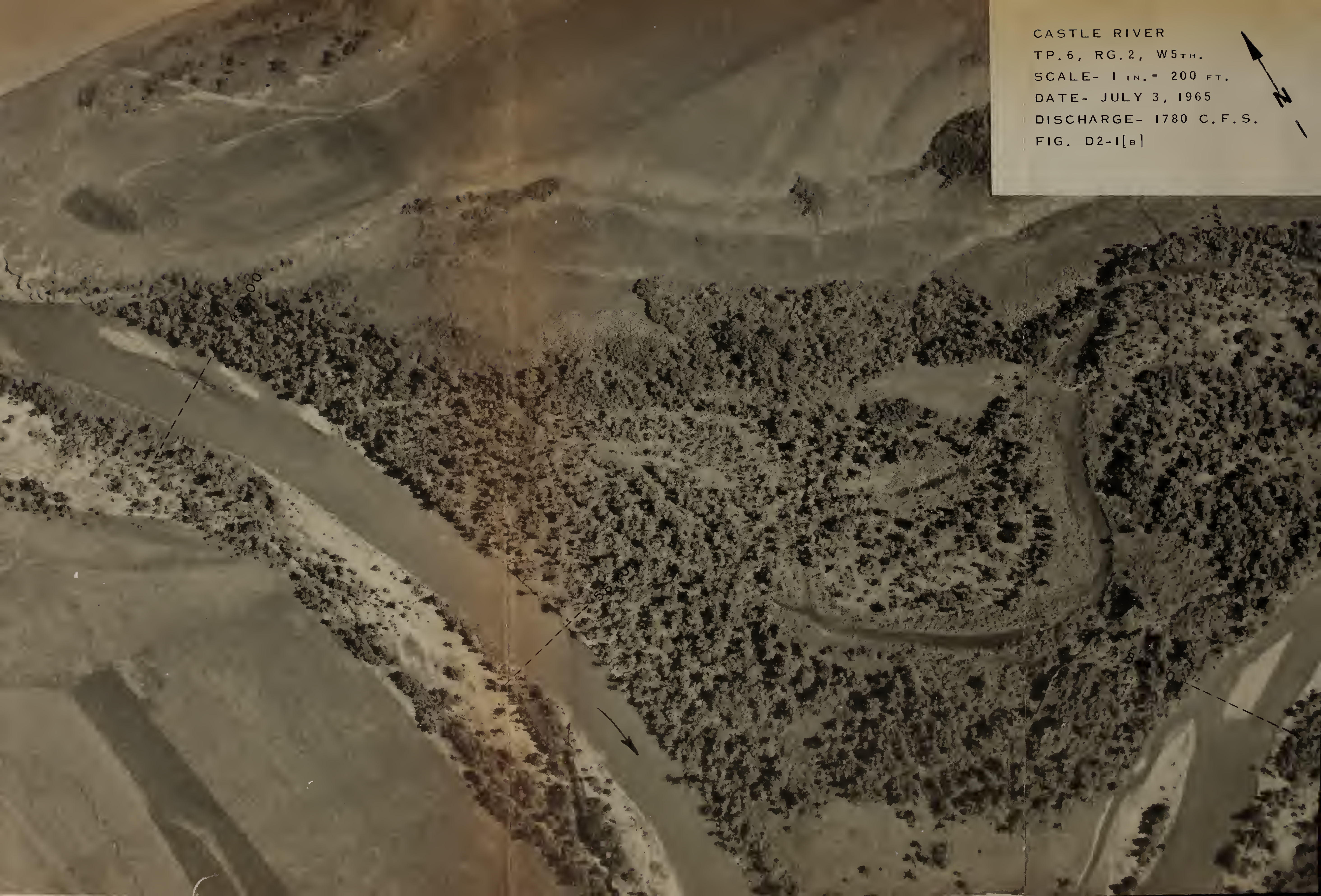
PHOTOGRAPHS


8+25
3+25

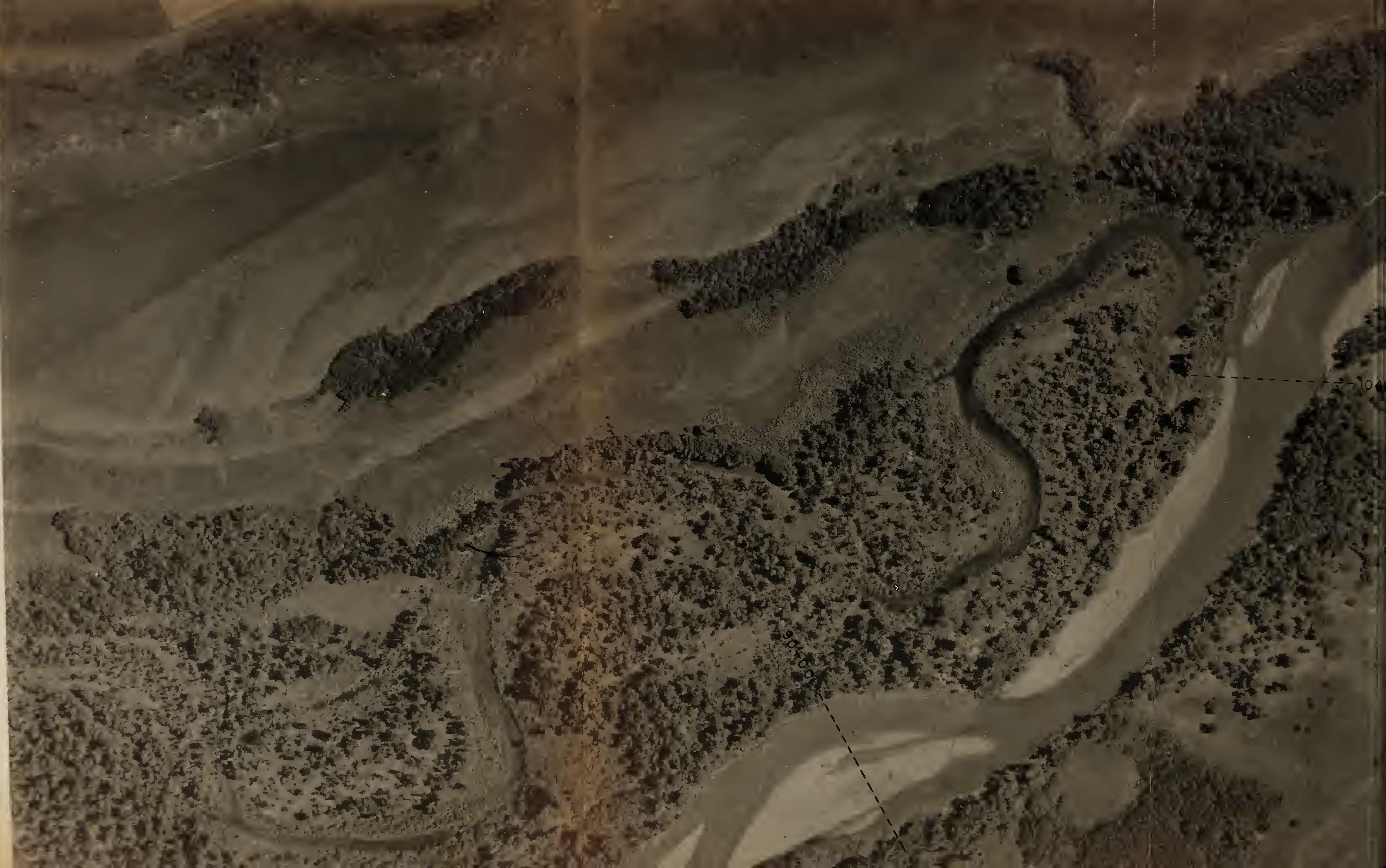


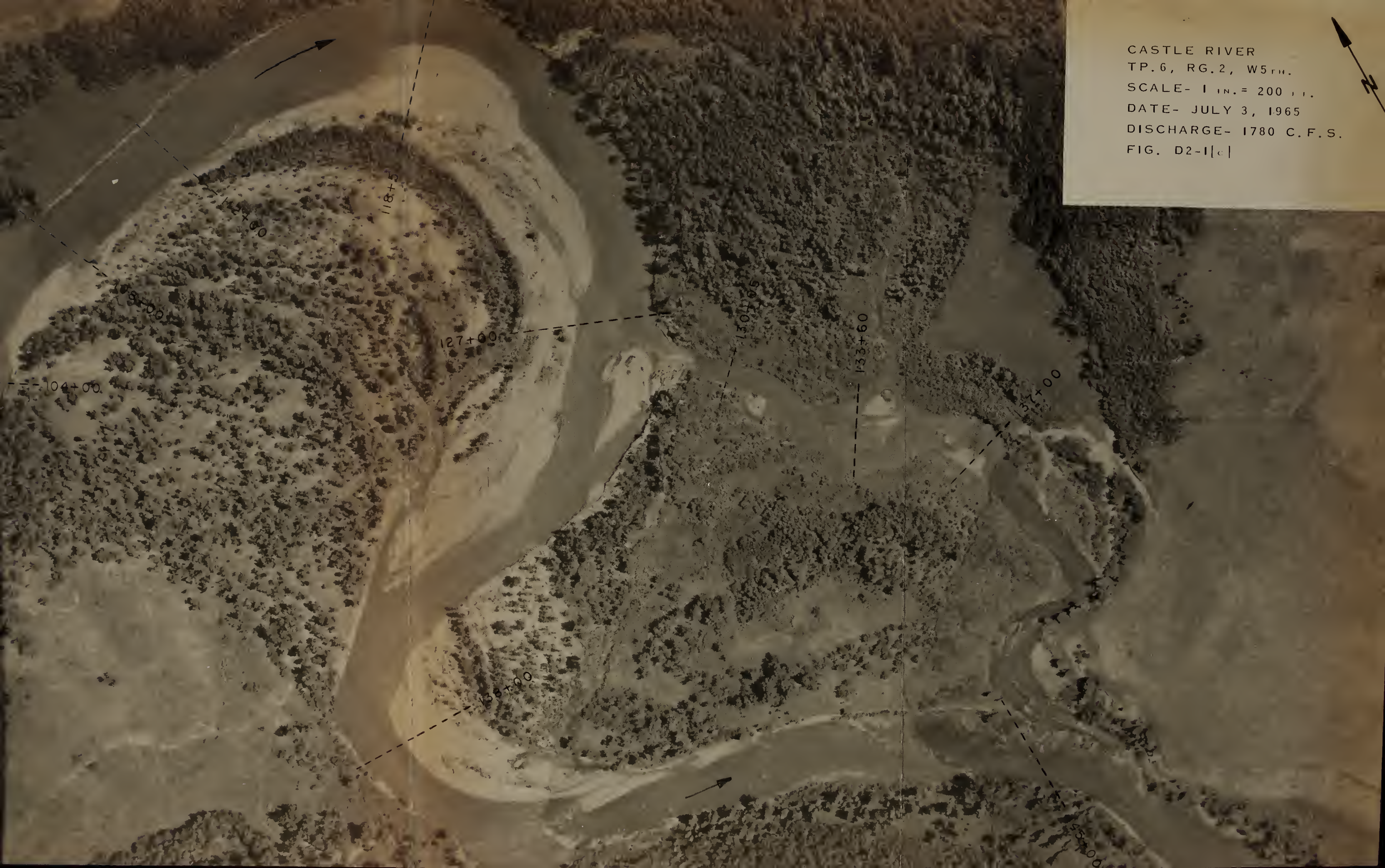
CASTLE RIVER
TP. 6, RG. 2, W5TH.
SCALE- 1 IN.= 200 FT.
DATE- AUGUST 1, 1965
DISCHARGE- 358 C.F.S.
FIG. D2-1(A)


20+00
31+00

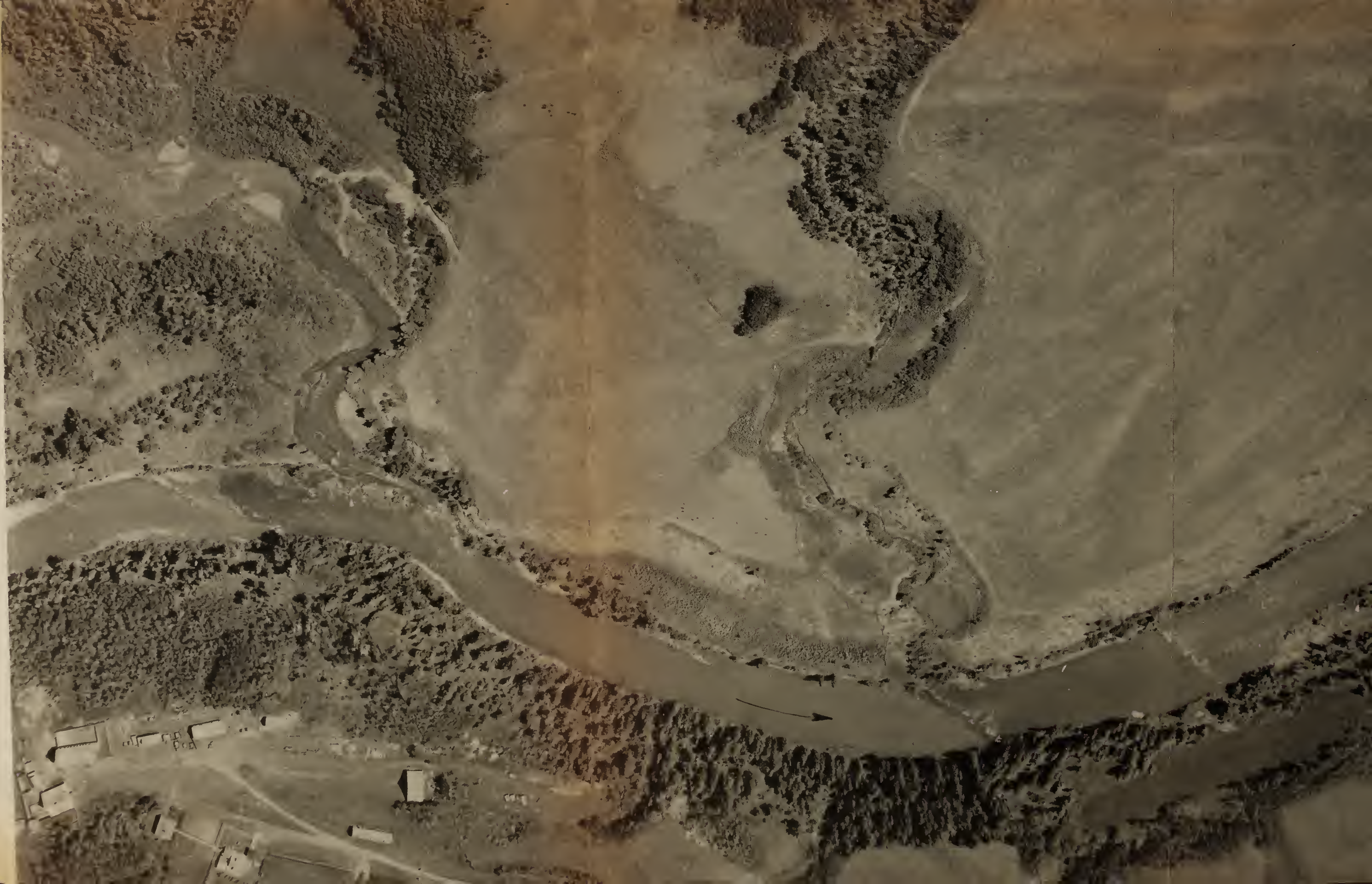


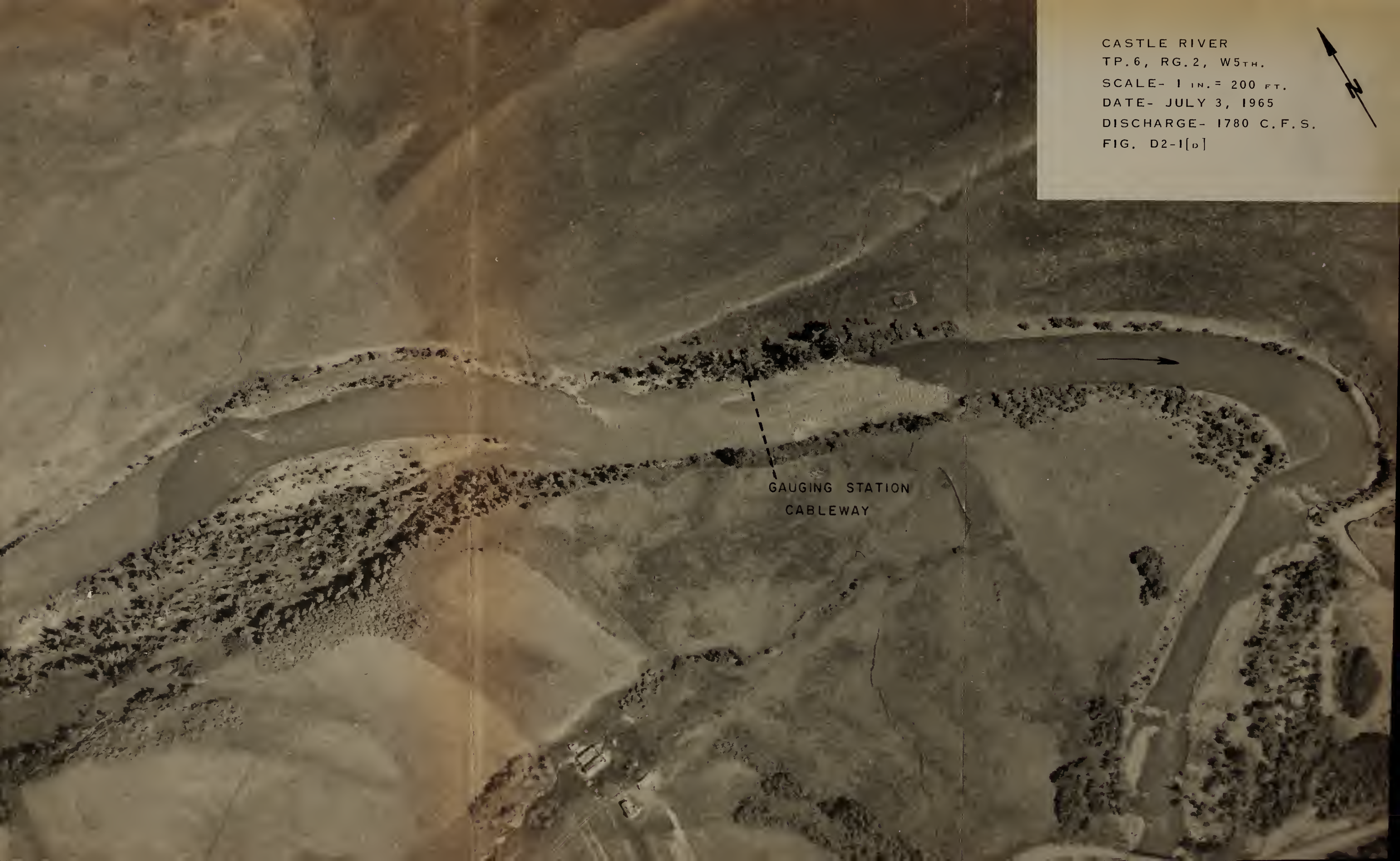
CASTLE RIVER
TP.6, RG.2, W5TH.
SCALE- 1 IN.= 200 FT.
DATE- JULY 3, 1965
DISCHARGE- 1780 C.F.S.
FIG. D2-1[B]


90+00
104

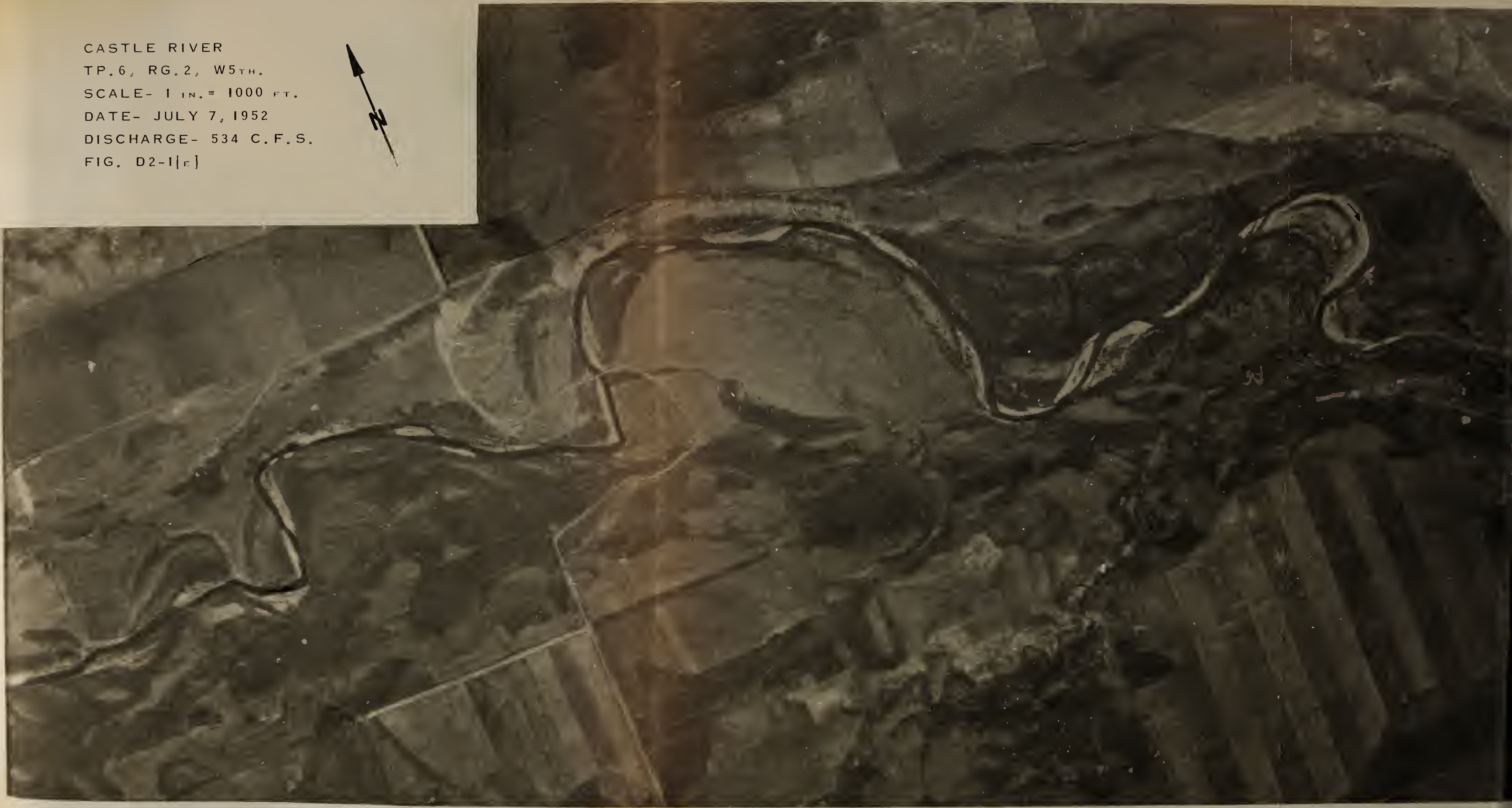


CASTLE RIVER
TP.6, RG.2, W5TH.
SCALE- 1 IN.= 200 FT.
DATE- JULY 3, 1965
DISCHARGE- 1780 C.F.S.
FIG. D2-1(c)

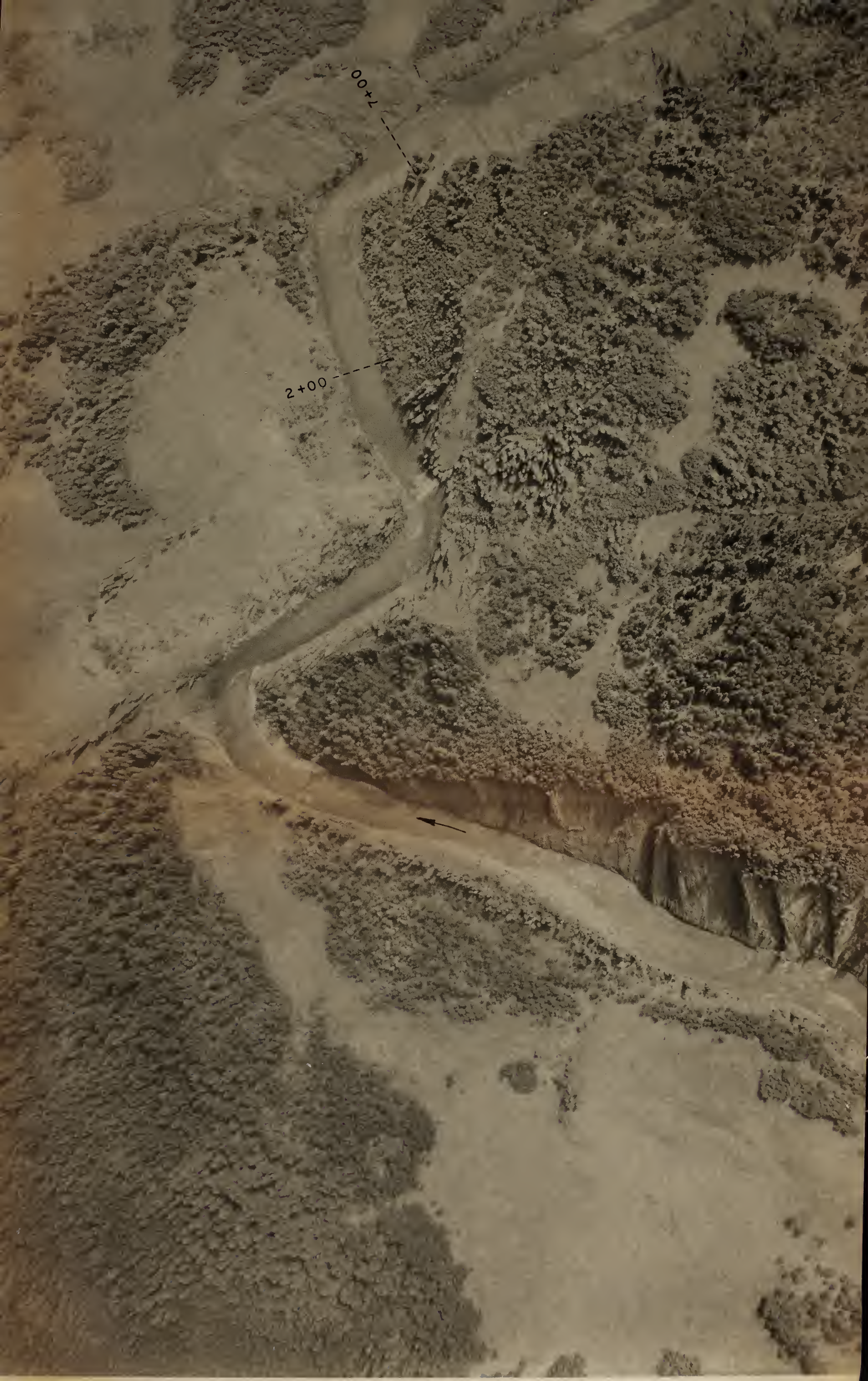


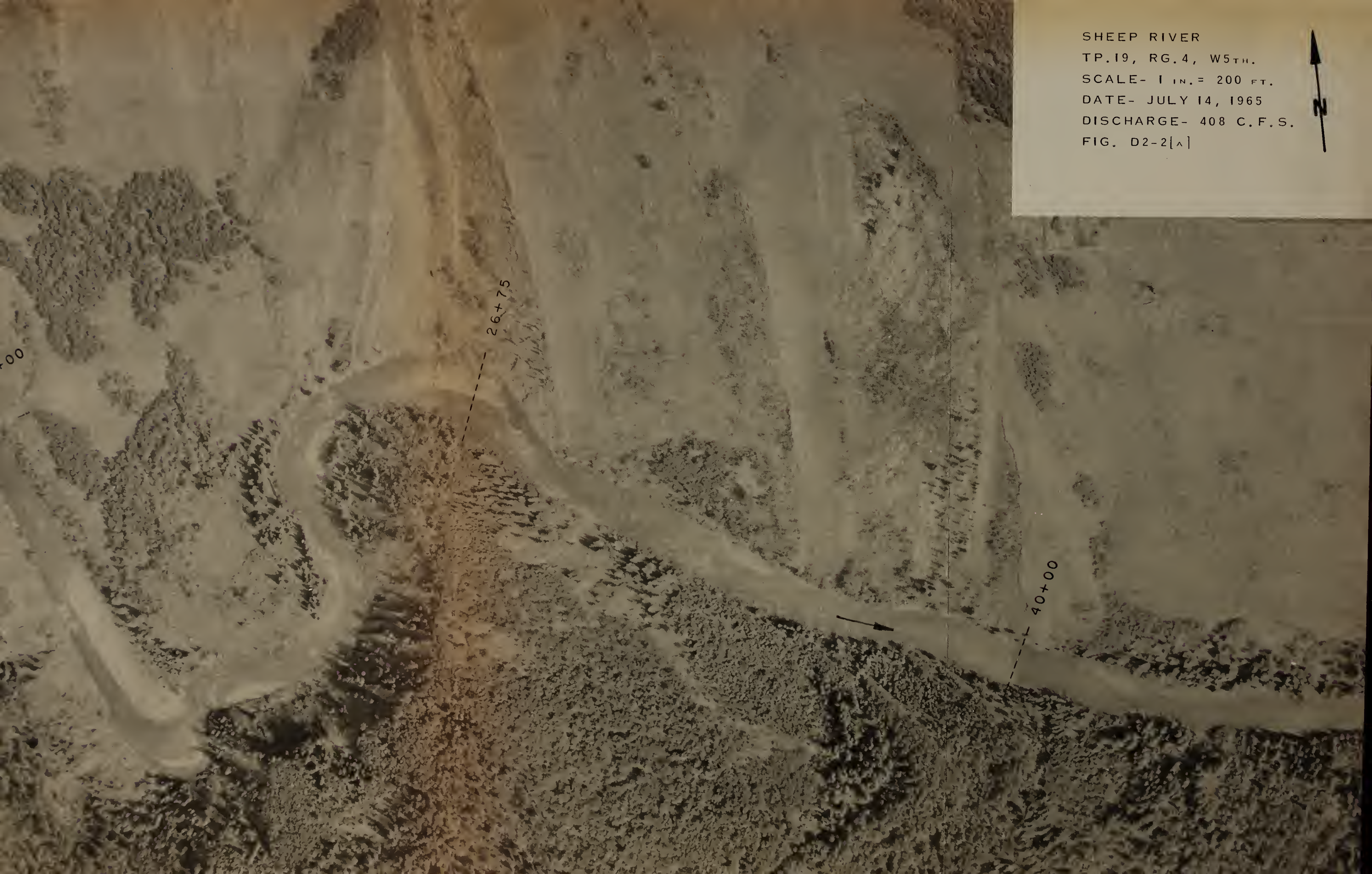


CASTLE RIVER
TP.6, RG.2, W5TH.
SCALE- 1 IN.= 200 FT.
DATE- JULY 3, 1965
DISCHARGE- 1780 C.F.S.
FIG. D2-1[D]

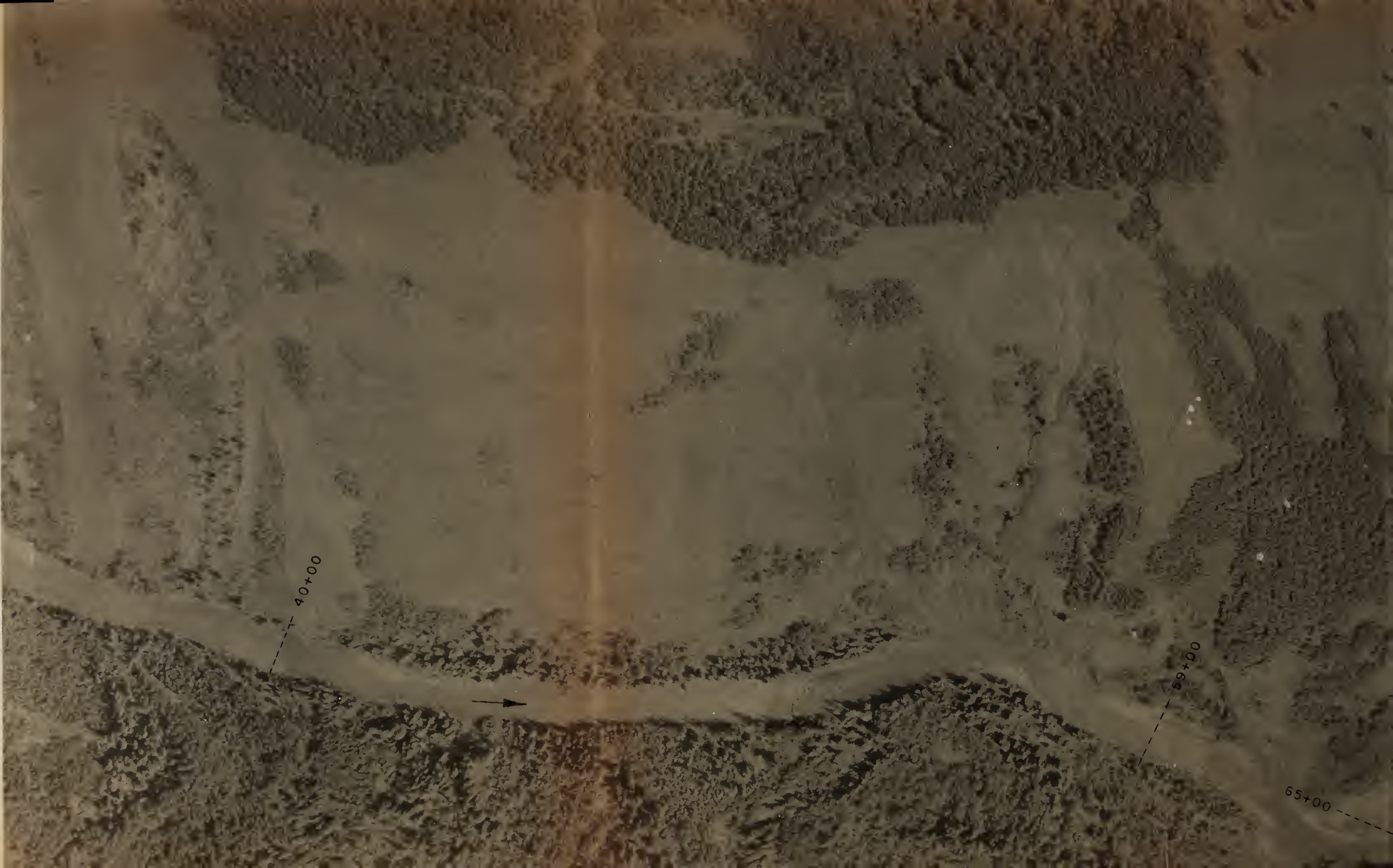


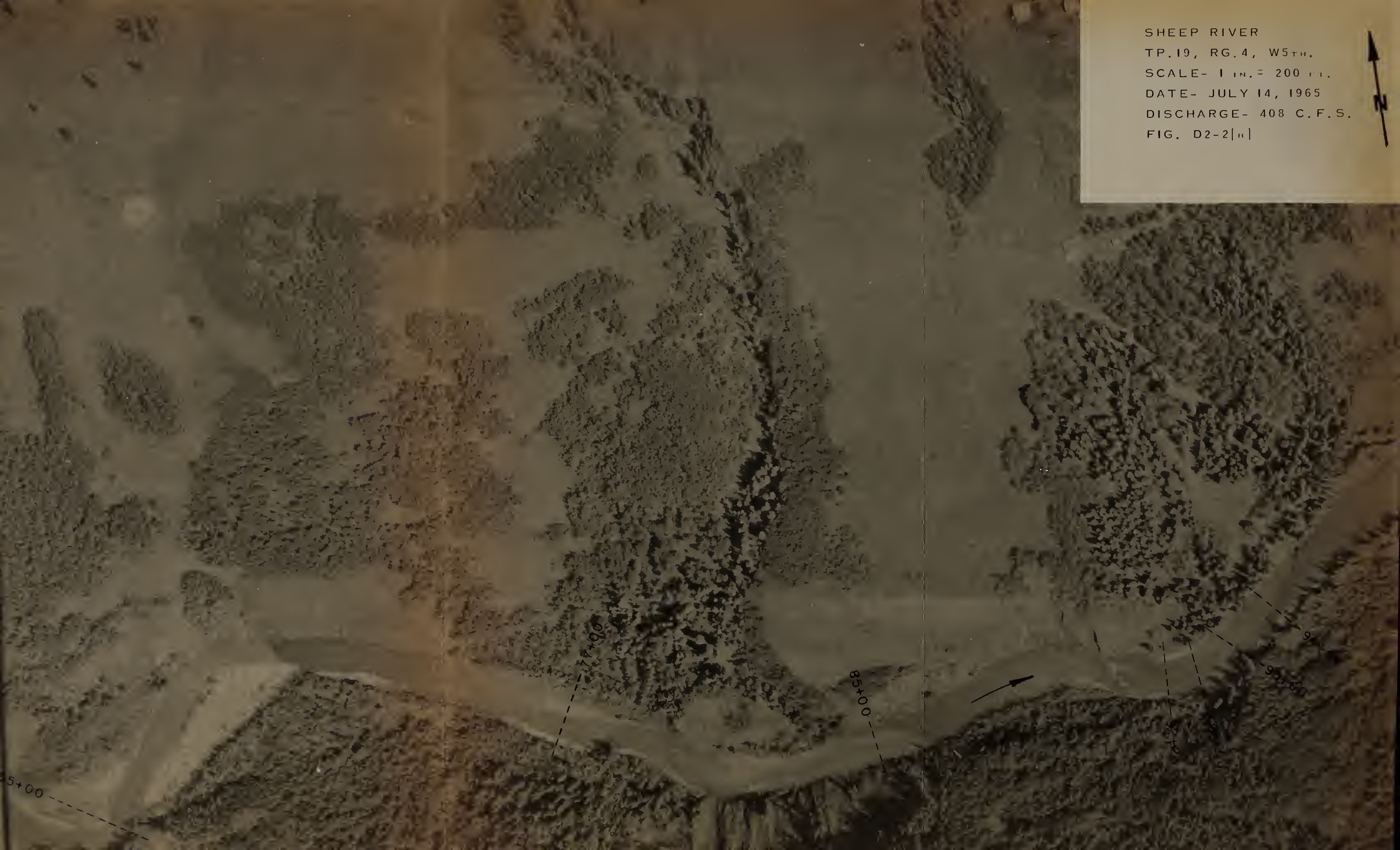
CASTLE RIVER
TP.6, RG.2, W5TH.
SCALE- 1 IN.= 1000 FT.
DATE- JULY 7, 1952
DISCHARGE- 534 C.F.S.
FIG. D2-1[E]

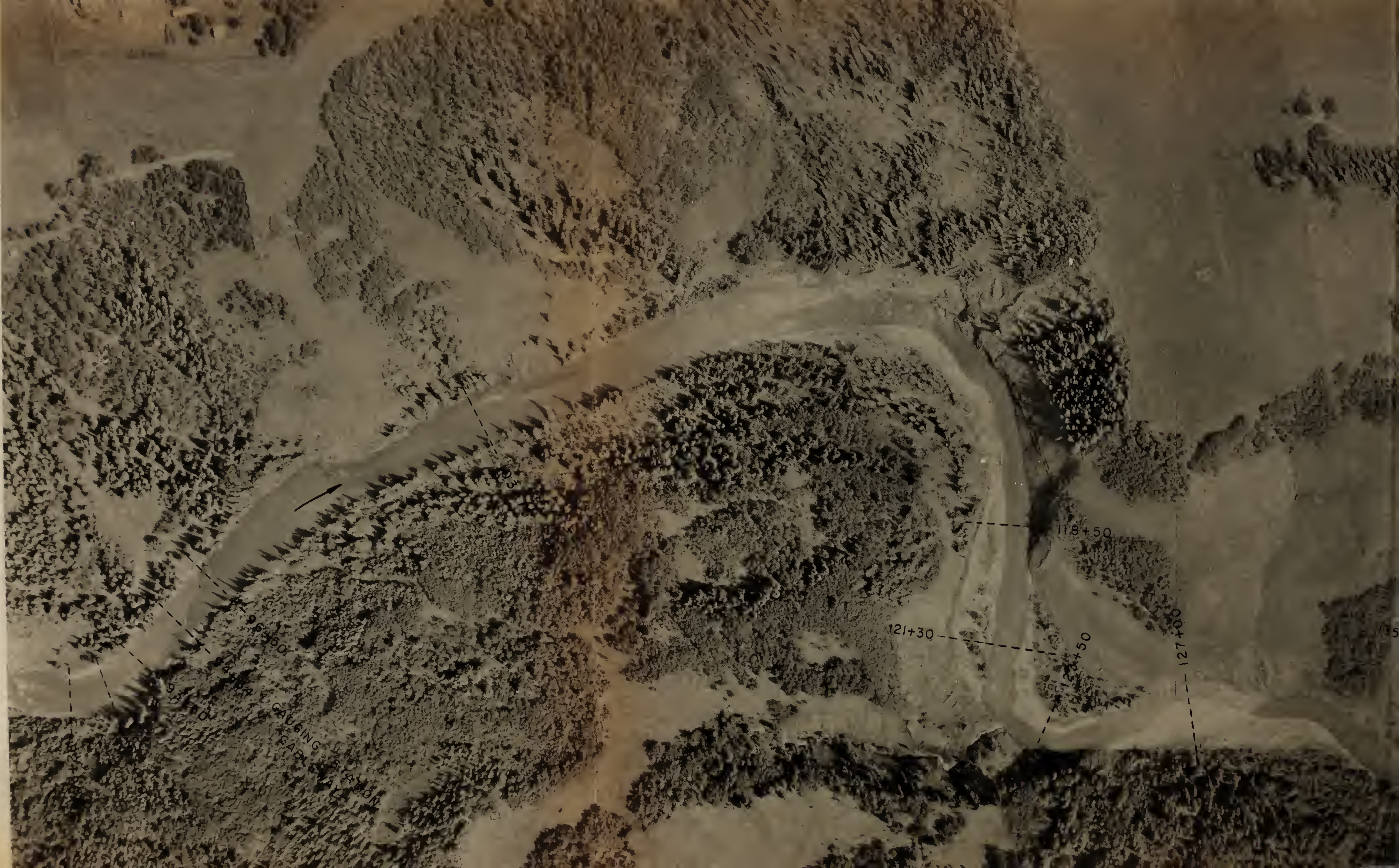

7+00
2+00

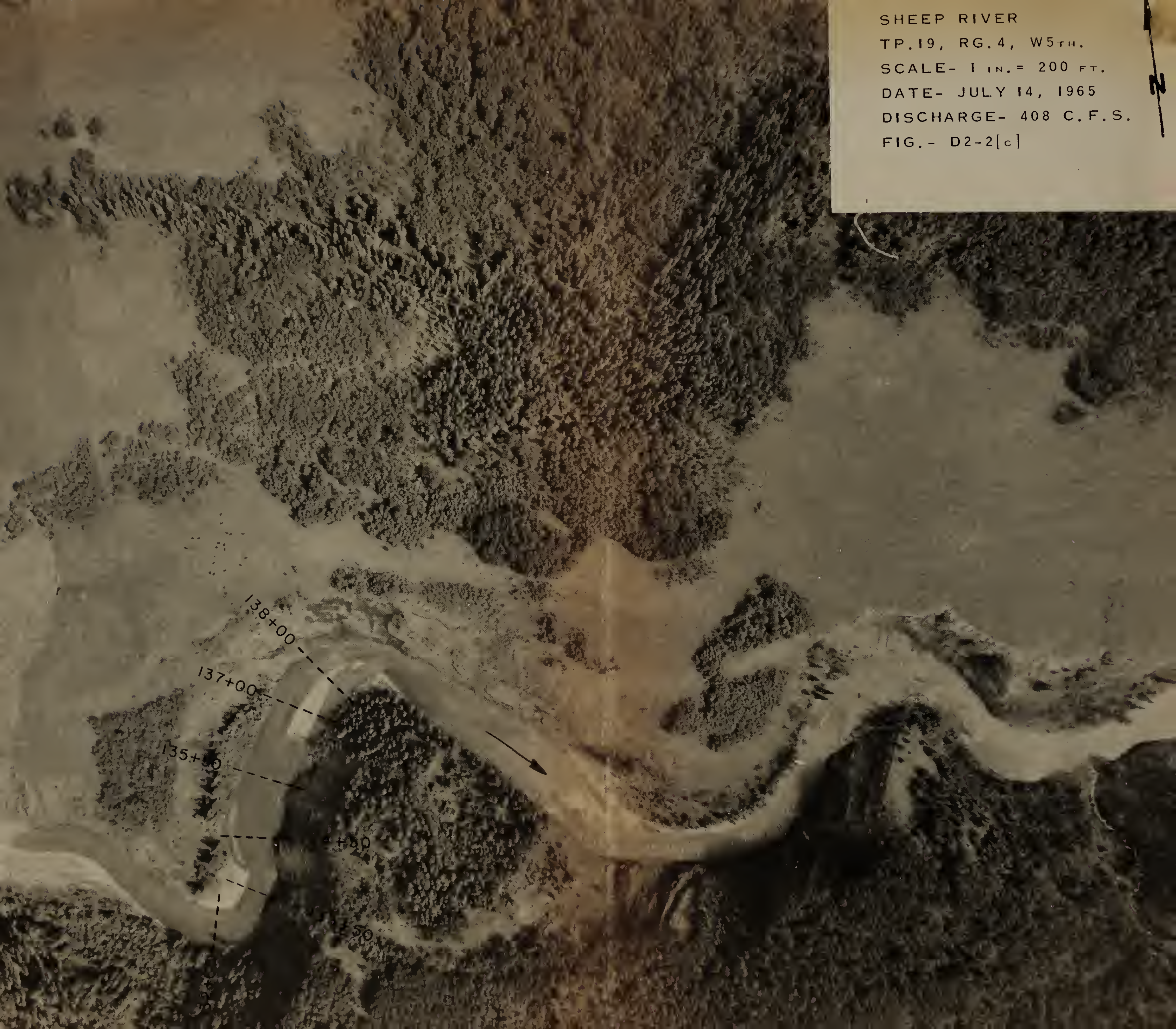


SHEEP RIVER
TP.19, RG.4, W5TH.
SCALE- 1 IN.= 200 FT.
DATE- JULY 14, 1965
DISCHARGE- 408 C.F.S.
FIG. D2-2[A]

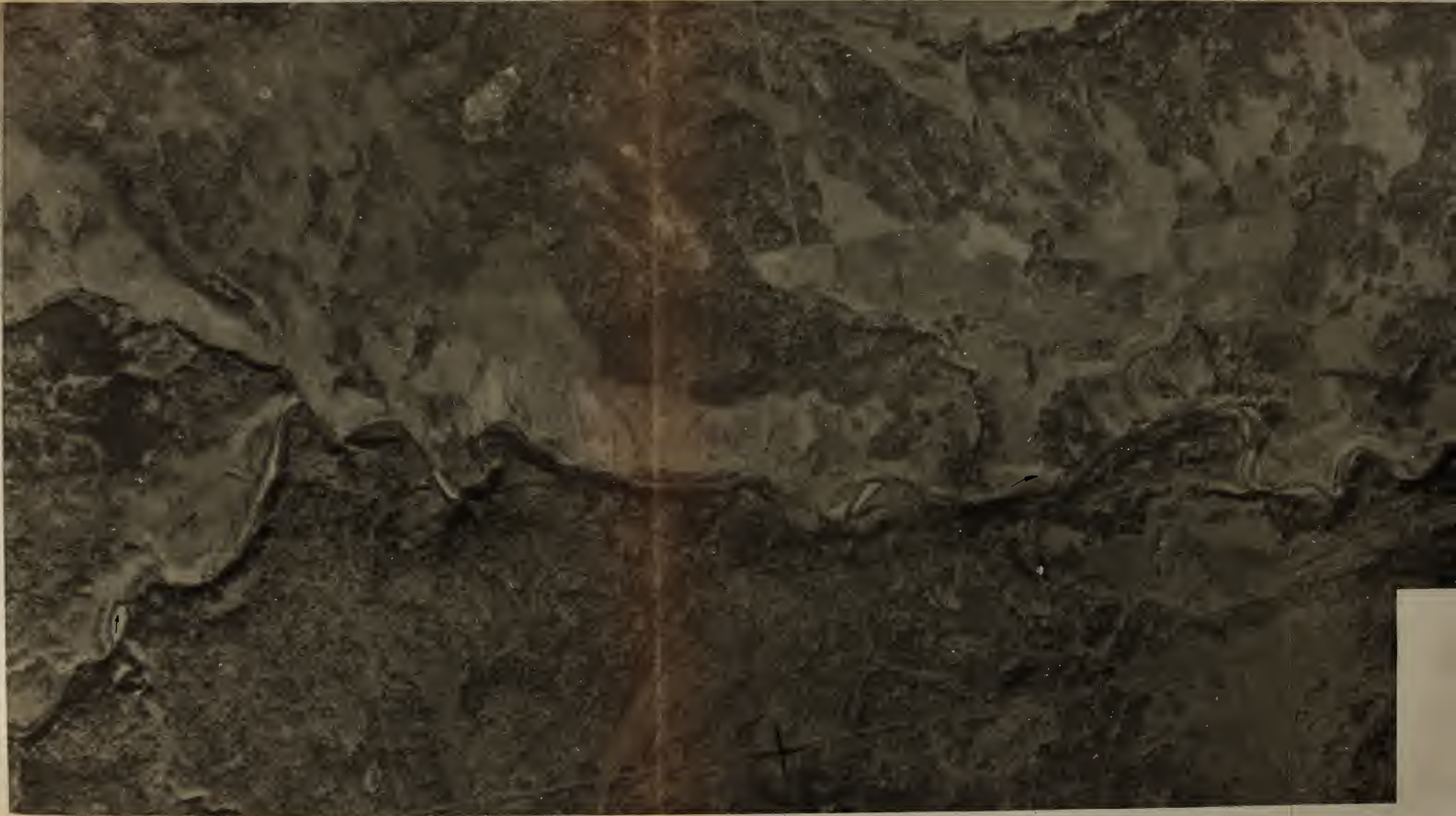

40+00
59+00
65+00

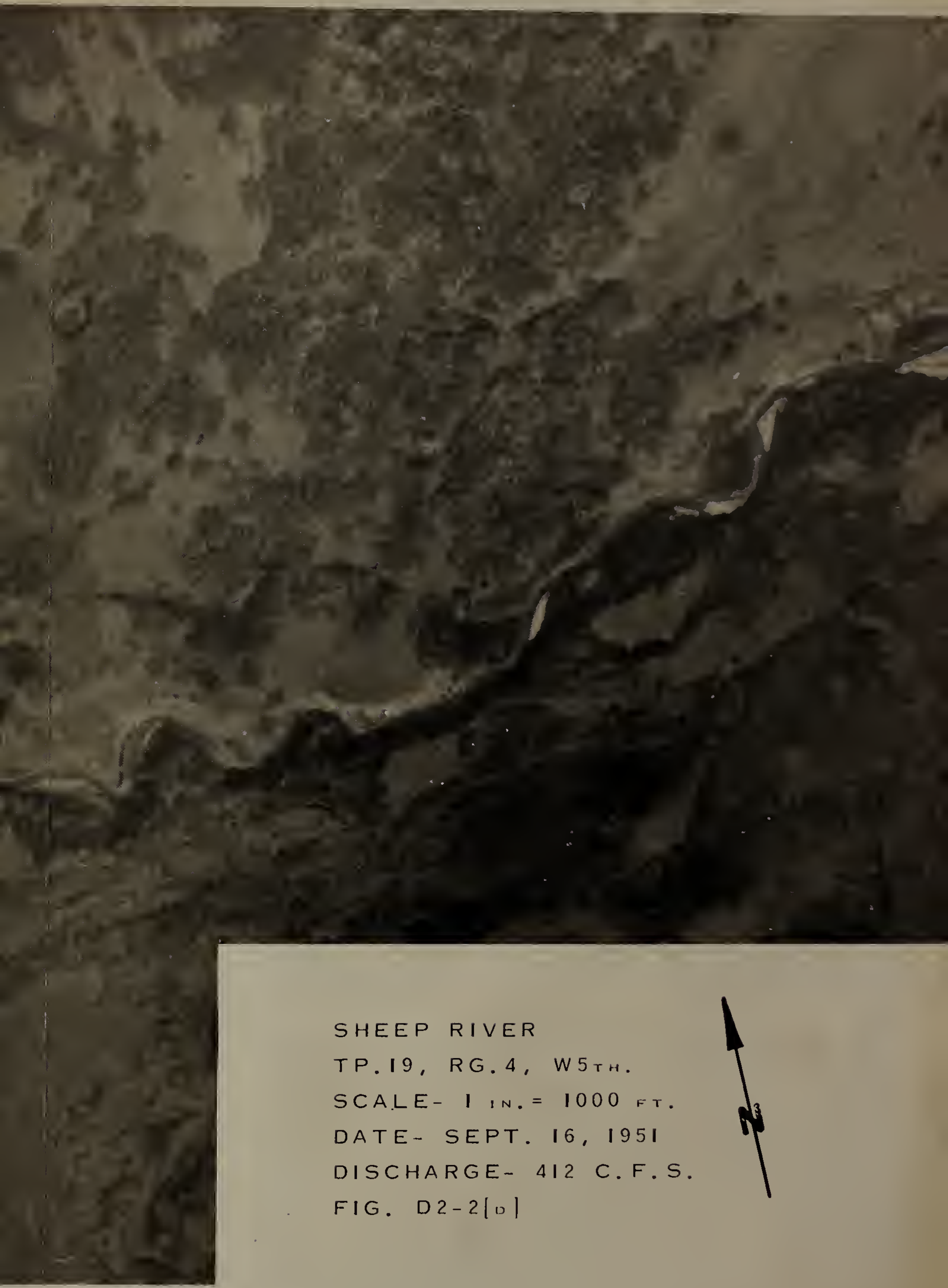

SHEEP RIVER
TP.19, RG.4, W5TH.
SCALE- 1 IN.= 200 FT.
DATE- JULY 14, 1965
DISCHARGE- 408 C.F.S.
FIG. D2-2(H)


103
118+50
121+30
123+50
127+00
135
96+50
93+00
GAGING STATION
CABLEWAY



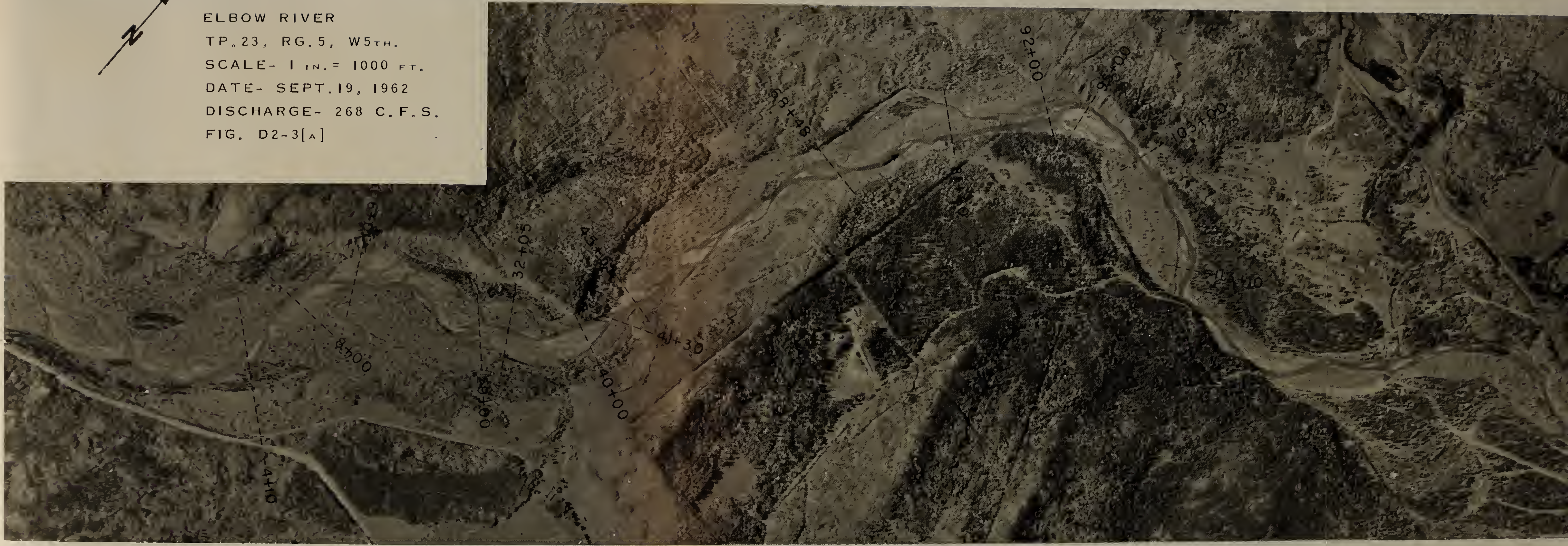
SHEEP RIVER
TP.19, RG.4, W5TH.
SCALE- 1 IN.= 200 FT.
DATE- JULY 14, 1965
DISCHARGE- 408 C.F.S.
FIG.- D2-2[c]

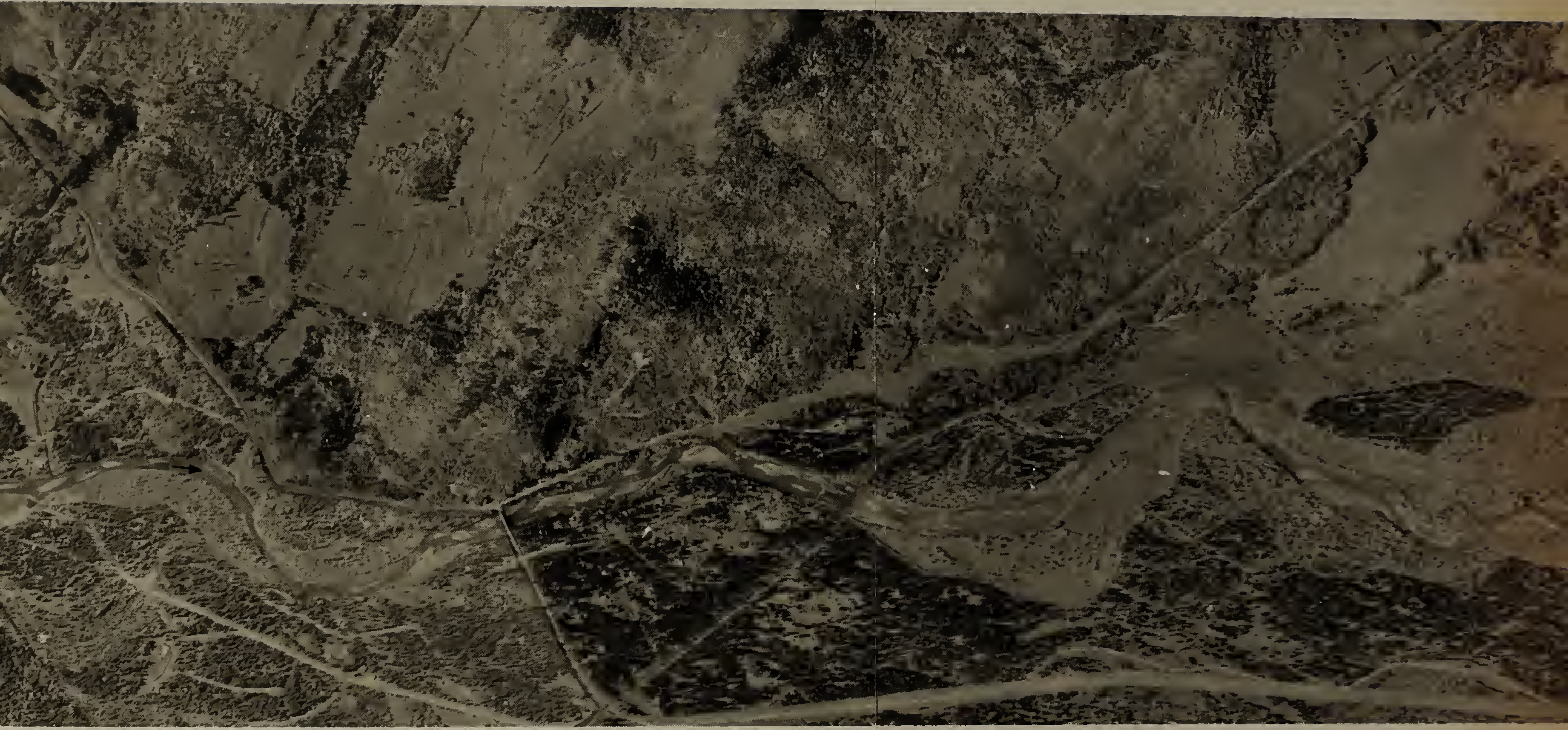


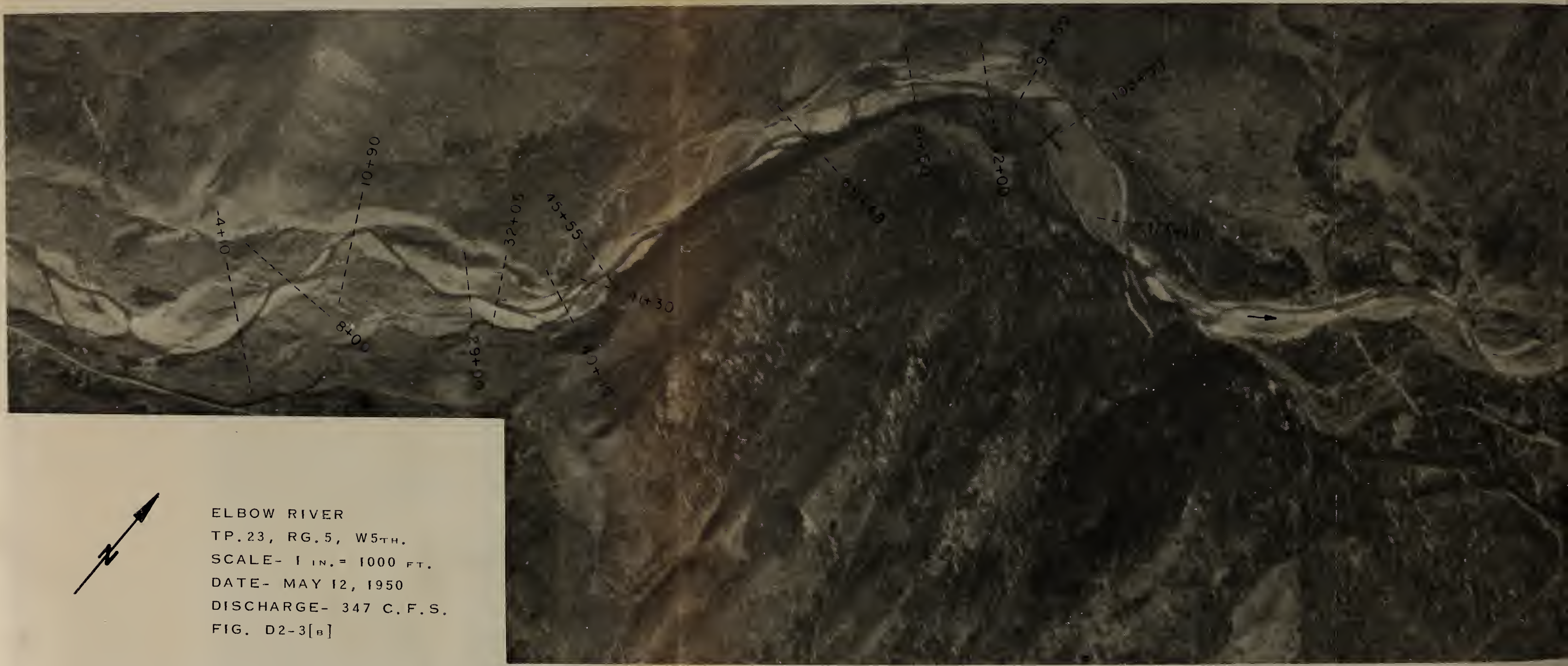


SHEEP RIVER
TP.19, RG.4, W5TH.
SCALE- 1 IN.= 1000 FT.
DATE- SEPT. 16, 1951
DISCHARGE- 412 C.F.S.
FIG. D2-2[D]

ELBOW RIVER
TP. 23, RG. 5, W5TH.
SCALE- 1 IN. = 1000 FT.
DATE- SEPT. 19, 1962
DISCHARGE- 268 C.F.S.
FIG. D2-3[A]







ELBOW RIVER
TP. 23, RG. 5, W5TH.
SCALE- 1 IN. = 1000 FT.
DATE- MAY 12, 1950
DISCHARGE- 347 C.F.S.
FIG. D2-3[B]

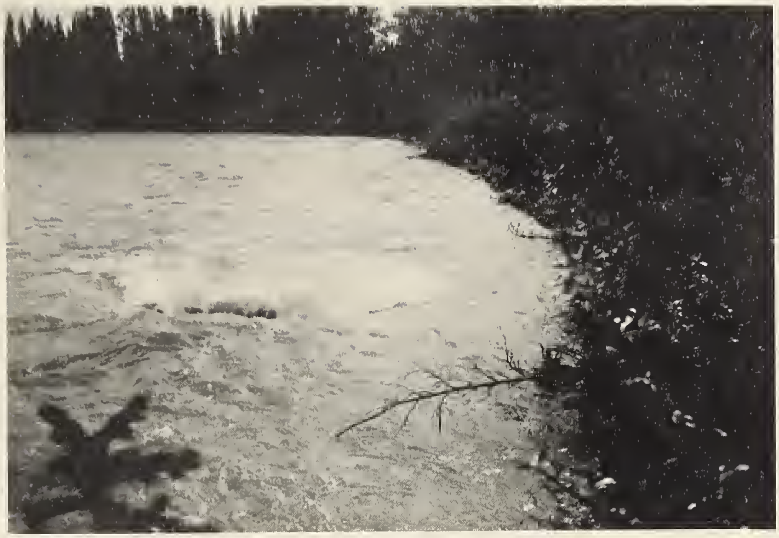


PLATE D2-4

LOOKING D/S ALONG BANK EROSION SITE X

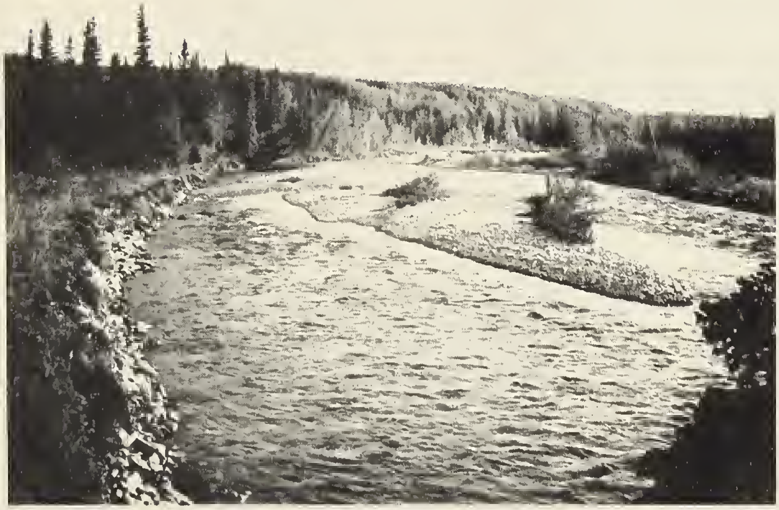
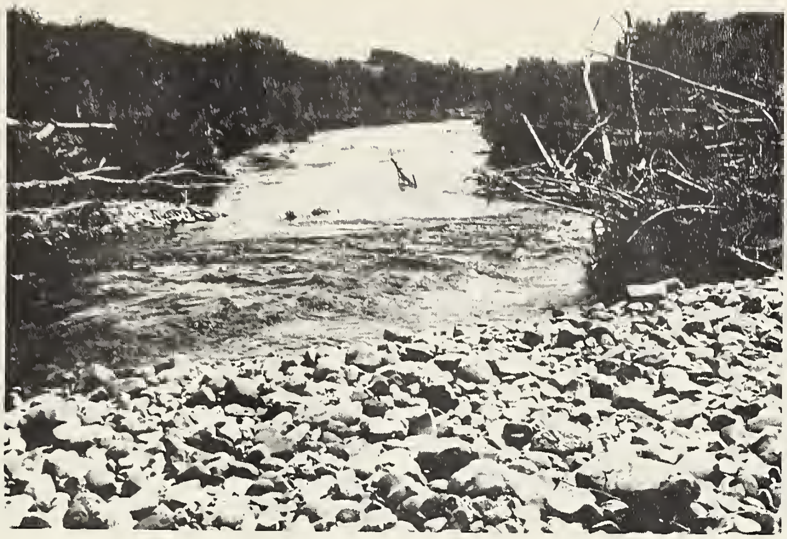


PLATE D2-5

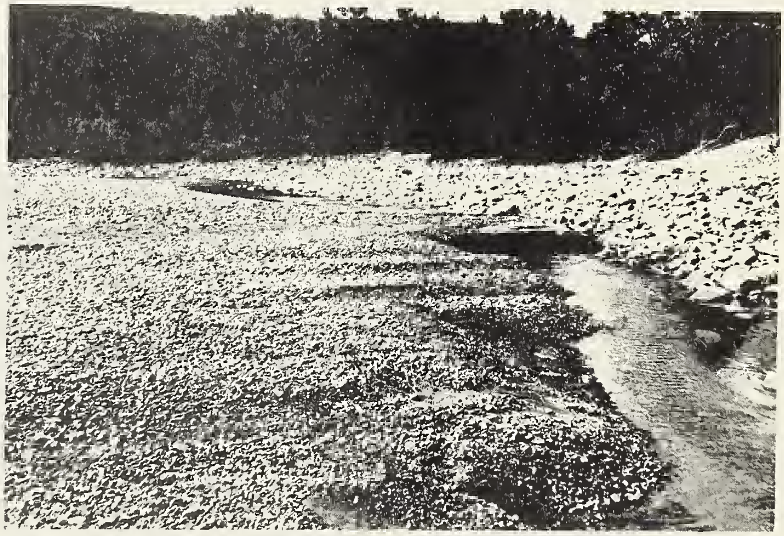
LOOKING U/S ALONG BANK EROSION SITE Y

CASTLE RIVER PHOTOGRAPHS

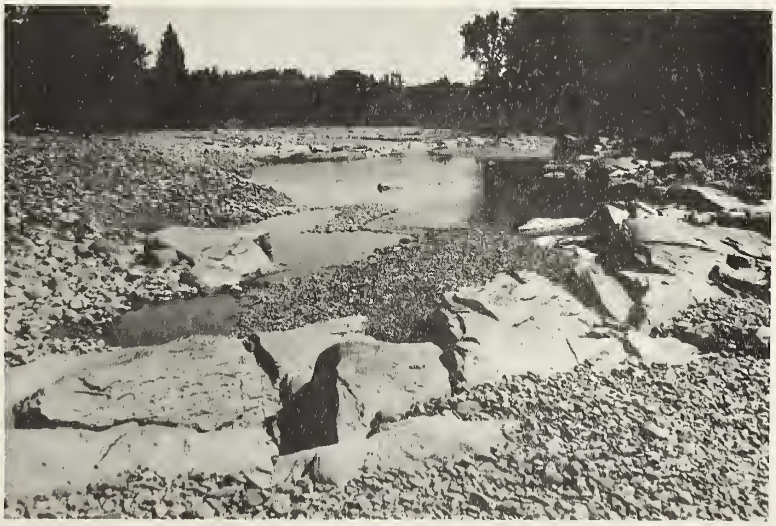
PHOTOGRAPH	DESCRIPTION	DATE
CA-1	Looking D/S from Sta. 127+00 along new cut-off channel. Material in foreground was analysed by sample CA-10-T. Q = 224 cfs.	8/19/65
CA-2	Looking D/S along old channel. Material on outside of bend was analysed by sample DCCA-2-T.	8/19/65
CA-3	Looking D/S along old channel from Sta. 139+00. Through this reach the rock outcrops controlled the slope.	8/19/65



CA-1



CA-2



CA-3

SHEEP RIVER PHOTOGRAPHS

PHOTOGRAPHS	DESCRIPTION	DATE
SH-1	Looking U/S towards head waters of Sheep River. Q = 3270 cfs.	6/18/65
SH-2	Looking U/S from Sta. 90+00 at 1:45 P.M. Notice the deeply incised reach between banks up to 200 feet high. Q = 3270 cfs.	6/18/65
SH-3	Looking D/S from Sta. 93+00 towards the guaging section marked by the cables. Q = 238 cfs.	8/13/65
SH-4	Looking U/S from Sta. 71+00 at 2:15 P.M. during high stage. Q = 3270 cfs.	6/18/65
SH-5	Looking U/S from Sta. 70+50. Notice the rapids that were drowned out during the high stage of Photo. SH-4 Q = 238 cfs.	8/13/65
SH-6	Notice the large material deposited near the U/S end of the point bar. This material is probably active at high discharges. Looking D/S from Sta. 120+75. Q = 350 cfs.	7/28/65

SH-1

SH-2

SH-3

SH-4

SH-5

SH-6

ELBOW RIVER PHOTOGRAPHS

PHOTOGRAPHS	DESCRIPTION	DATE
E-1	Looking U/S from Sta. 12+00. Notice the heavy turbulence as the flow undercuts the bank. Erosion line "X" is along bank in the upper left. Q = 4430 cfs.	6/18/65
E-2	Cutoff channel on left, main channel in background behind brush in center of picture. At this point the river was about 800 feet wide during the flood. Q = 4430 cfs.	6/18/65
E-3	Looking U/S from hill at about Sta. 40+00. Notice the braided pattern. Q = 242 cfs.	5/13/65
E-4	Looking U/S from same place as picture E-3 during high stage of June 18. Notice how the whole river flat is inundated. Q = 4430 cfs.	6/18/65
E-5	Same location as picture E-4. Notice the deposited drift material in the center of the picture. Note the new channel on the center right. Q = 488 cfs.	8/16/65
E-6	Looking D/S towards Sta. 68+00 which is opposite the rock outcrop. Main channel is just in front of trees in the water. Q = 4430 cfs.	6/18/65
E-7	Looking from near same spot as in photo E-6. Old channel trace is given by the two small streams near center of picture. Main channel after flood is at base of hill in foreground. Q = 488 cfs.	8/16/65
E-8	Looking U/S from Sta. 74+00. During the peak flow of the flood the bar was not visable. Q = 4430 cfs.	6/18/65

E-9	Looking U/S along the same reach as in photo E-8. The old channel, before the June flood, is marked by the backwater in the center right. Q = 488 cfs.	8/16/65
E-10	Looking D/S from Sta. 77+00 during the flood. Peak flood had covered most of the island. Quiet water in the left center. Q = 4430 cfs.	6/18/65
E-11	Looking from the same point as in photo E-10. Evidence of suspended load deposition was found to the right of the stagnant water near center of picture E-10. Q= 488 cfs.	8/16/65
E-12	Looking U/S from Sta. 118+00 during June 18 flood. Q = 4430 cfs.	6/18/65
E-13	Looking U/S from Sta. 118+00 as water is receeding. Notice new bar that was formed by the flood, extending from center of picture all the way around the bend. Main channel is where a gravel bar was previous to the flood. Q = 1300 cfs.	6/21/65
E-14	Looking U/S as in photo E-13. Notice the rock outcrop and how the gravel bar extends over it. Q = 488 cfs.	8/16/65

E-1

E-2

E - 3

E - 4

E - 5

E - 6

E - 7

E - 8

E-9

E-10

E-11

E-12

E-13

E-14

DRYWOOD CREEK PHOTOGRAPHS

PHOTOGRAPHS	DESCRIPTION	DATE
DR-1	Looking U/S to the drainage basin of Drywood Creek which lies in the gap to the center right.	5/15/65
DR-2	Looking U/S towards head of drainage basin from a point about three miles U/S of guaging station.	7/15/65
DR-3	Drywood Creek guaging station. Q = 34.6 cfs.	7/16/65
DR-4	Typical small log jam with undercutting of bank, scour hole and advancing point bar. Q = 34.6 cfs.	7/15/65
DR-5	Looking U/S from Sta. 8+00. Typical broad, swift, shallow, rapid reach. Q = 34.6 cfs.	7/15/65
DR-6	Looking D/S from Sta. 16+25. Notice the large rocks near the head of the rapids. Q = 34.6 cfs.	7/15/65
DR-7	Looking U/S from Sta. 43+50. Here the creek had a relatively wide flood plain shown in the center of the photo. Q = 56.1 cfs.	5/15/65
DR-8	Looking D/S from Sta. 70+50 towards gravel bar. Notice the widening of the stream. Q = 34.6 cfs.	7/15/65
DR-9	Field book indicates size of material on bar shown in photo DR-10.	7/15/65
DR-10	Looking D/S from Sta. 75+00. Notice numerous point bars in this reach. Q = 34.6 cfs.	7/15/65
DR-11	Looking D/S from Sta. 81+50 at slumping banks caused by seepage and undercutting. Q = 34.6 cfs.	7/15/65
DR-12	Looking D/S from Sta. 120+00 towards reservoir shown in background. Notice the incised channel and the much finer bed material than further upstream. Q = 34.6 cfs.	7/15/65

DR-1

DR-2

DR-3

DR-4

DR-5

DR-6

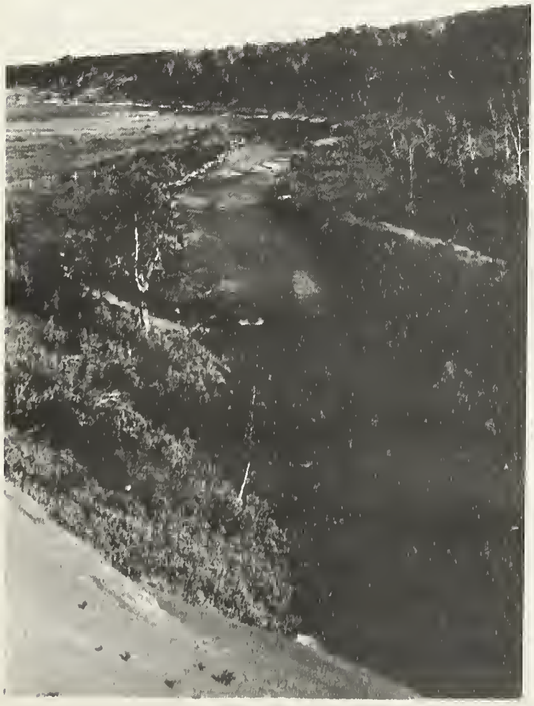
DR-7

DR-8

DR-9

DR-10

DR-11



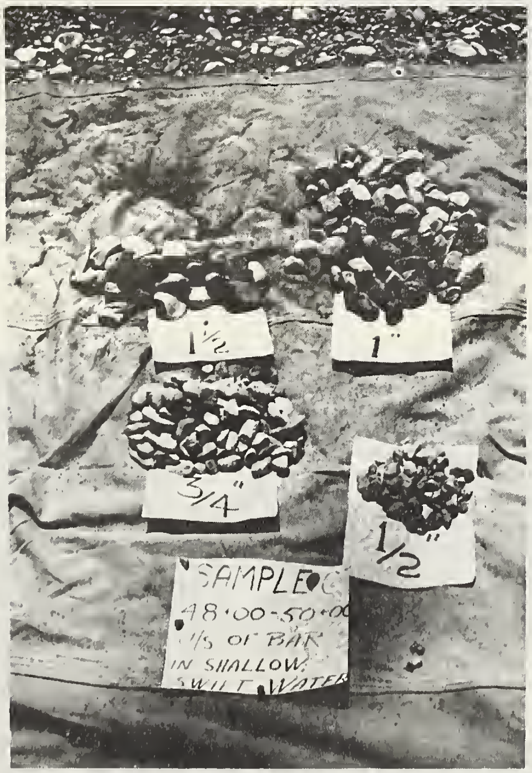
DR-12

RECOVERED COLORED ROCKS

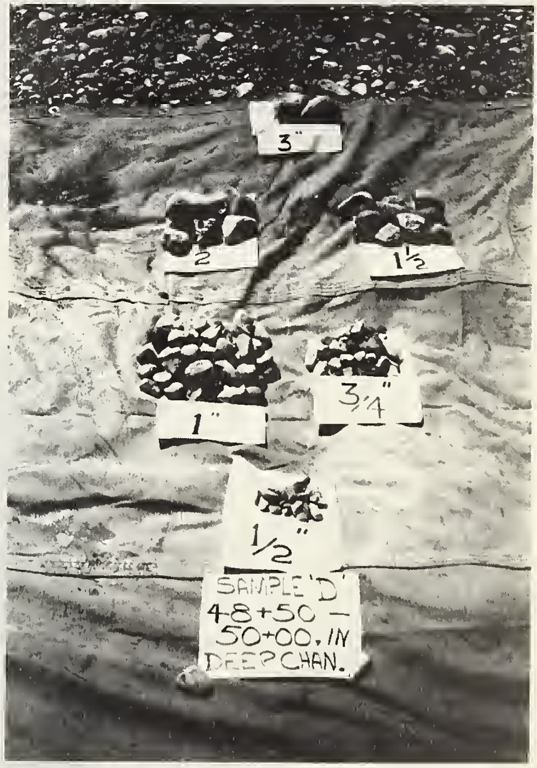
PHOTOGRAPH	DESCRIPTION	DATE
	ELBOW RIVER	
CR-1	Colored rock recovery sample "A"	6/10/65
CR-2	Colored rock recovery sample "B"	6/10/65
CR-3	Colored rock recovery sample "C"	6/10/65
CR-4	Colored rock recovery sample "C"	6/10/65
	DRYWOOD CREEK	
CR-5	Colored rocks at initial placement site.	5/18/65
CR-6	Colored rock recovery from Sta. 12+75.	7/8/65
CR-7	Colored rock recovery from Sta. 12+85 to 13+10.	7/8/65
CR-8	Colored rock recovery from Sta. 18+00 to 21+00.	7/8/65
CR-9	Colored rock recovery from Sta. 27+00 to 28+00.	7/8/65
CR-10	Colored rock recovery from Sta. 50+50 to 104+00.	7/8/65

CR-1

CR-2



CR-3



CR-4

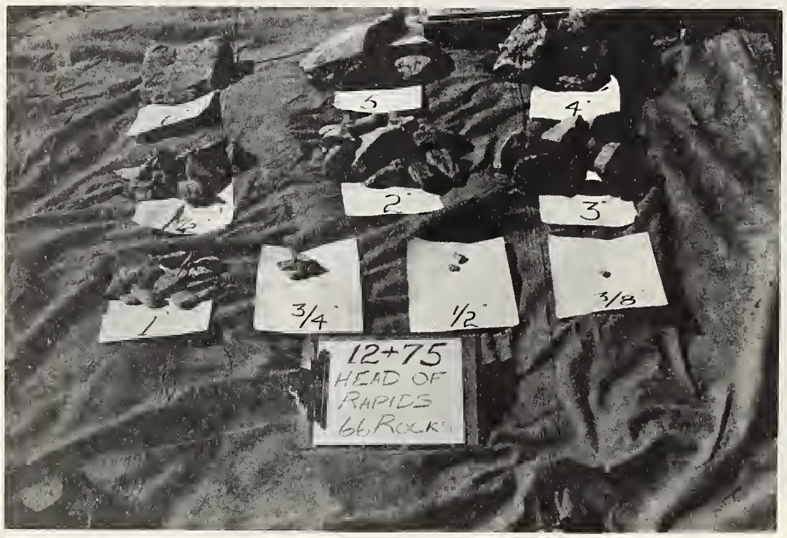
[illegible]

[illegible]

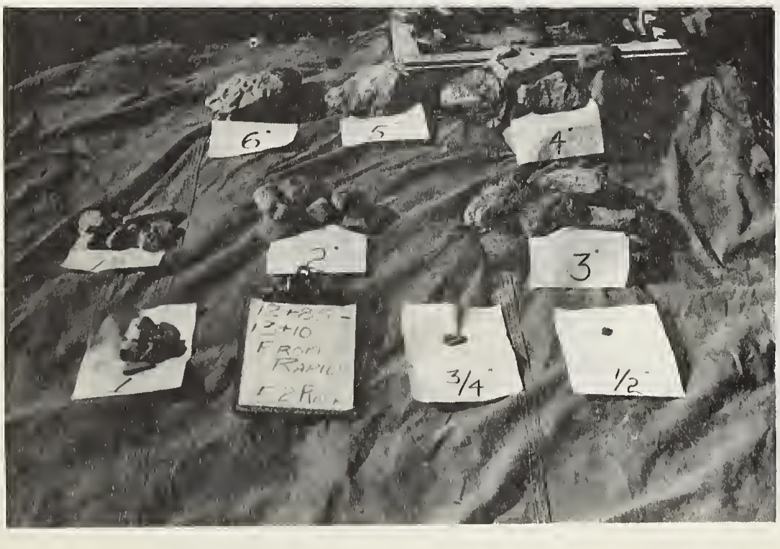
[illegible]

[illegible]

CR-5


5"
4"
2"
3"
1"
3/4"
1/2"
3/8"
12+75
HEAD OF
RAPIDS
66 ROCKS

CR-6

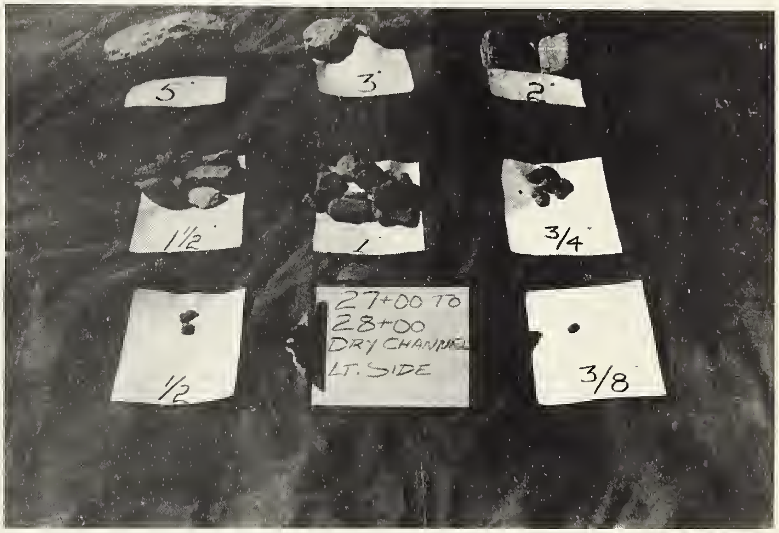

6"
5"
4"
2"
3"
1"
12+85 -
13+10
FROM
RAPIDS
3/4"
1/2"

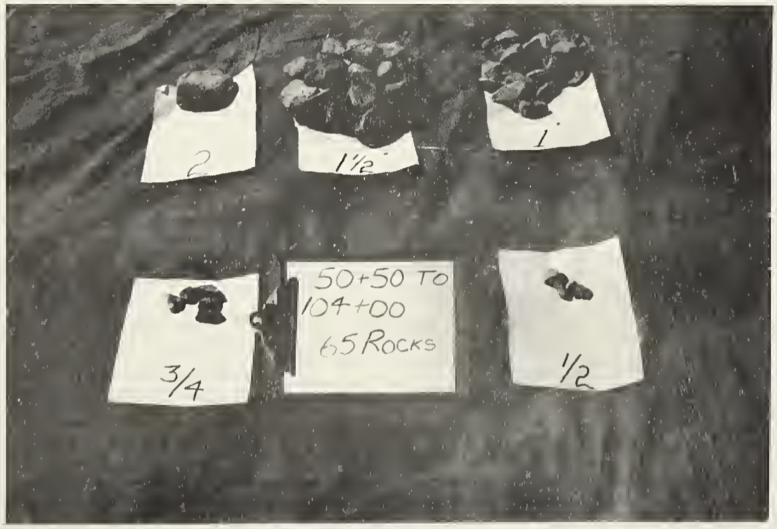
CR-7

2"
1½"
1"
¾"
8+00-21+00
MID CHANNEL
½

CR-8

CR-9


5"
3"
2"
1½"
1"
¾"
½
27+00 TO
28+00
DRY CHANNEL
LT. SIDE
3/8


2
1½"
1"
¾
50+50 TO
104+00
65 ROCKS
½

CR-10

APPENDIX E

DATA SOURCE DESCRIPTIONS

DATA FOR NON-DIMENSIONAL PLOTS IN SECTION 6-2

(a) Elbow River field data: This data came from the colored rock recovery operations. At the time the rocks were being recovered, it was noticed that in most cases the stones would move a considerable distance when disturbed. They were more or less at the stage of incipient motion.

The size of stone used in the plots was D_{90W} based on sieve analysis by weight of the recovered stones. It was assumed that D_{90W} would give the best approximation to the size of stones with incipient motion.

The bed material was well graded; the median size was larger than the colored stones moving over it.

(b) Ref. 20, U.S.G.S. Prof. Paper 282-G: This data comes from flume experiments using .67 mm. and 2 mm. sands. Only values indicated as occurring at incipient motion were used.

The particles in the state of incipient motion differentiated out from the nearly uniform bed material.

(c) Ref. 2, Laboratory data using 1.7 mm. "gravel": The data comes from flume studies in which the F_{bo} of the bed material was being studied. The values used are based on what Quershi considered as F_{bo} conditions.

The particles in incipient motion differentiated out from the uniform bed material.

(d) Ref. 19 Laboratory data using 1.7 mm. "gravel": The data is based on the same material as in (c). The experiments were carried out in a smaller flume. Only selected results were used which fitted the more reliable data of Quershi.

(e) Ref. 21 Screen-caught samples - Field data: Fahnestock's screen-caught samples were taken by placing a screen in the path of material moving along the channel bed. The larger fractions were measured and indicated the competence of the stream.

The bed in most cases was a pavement of fine gravel and sand with the large material moving over it.

The results of the sampling are not truly compatible with the previous recorded data. These stones were in actual motion, whereas, in all the other cases, they were on the verge of motion. This would indicate that the results of the analysis of the data should plot lower than indicated in Fig. C6-70.

(f) Ref. 21 Samples from bars - Field data: This data came from sampling large material deposited on top of bars. The hydraulic conditions just U/S of the bar were used in calculations.

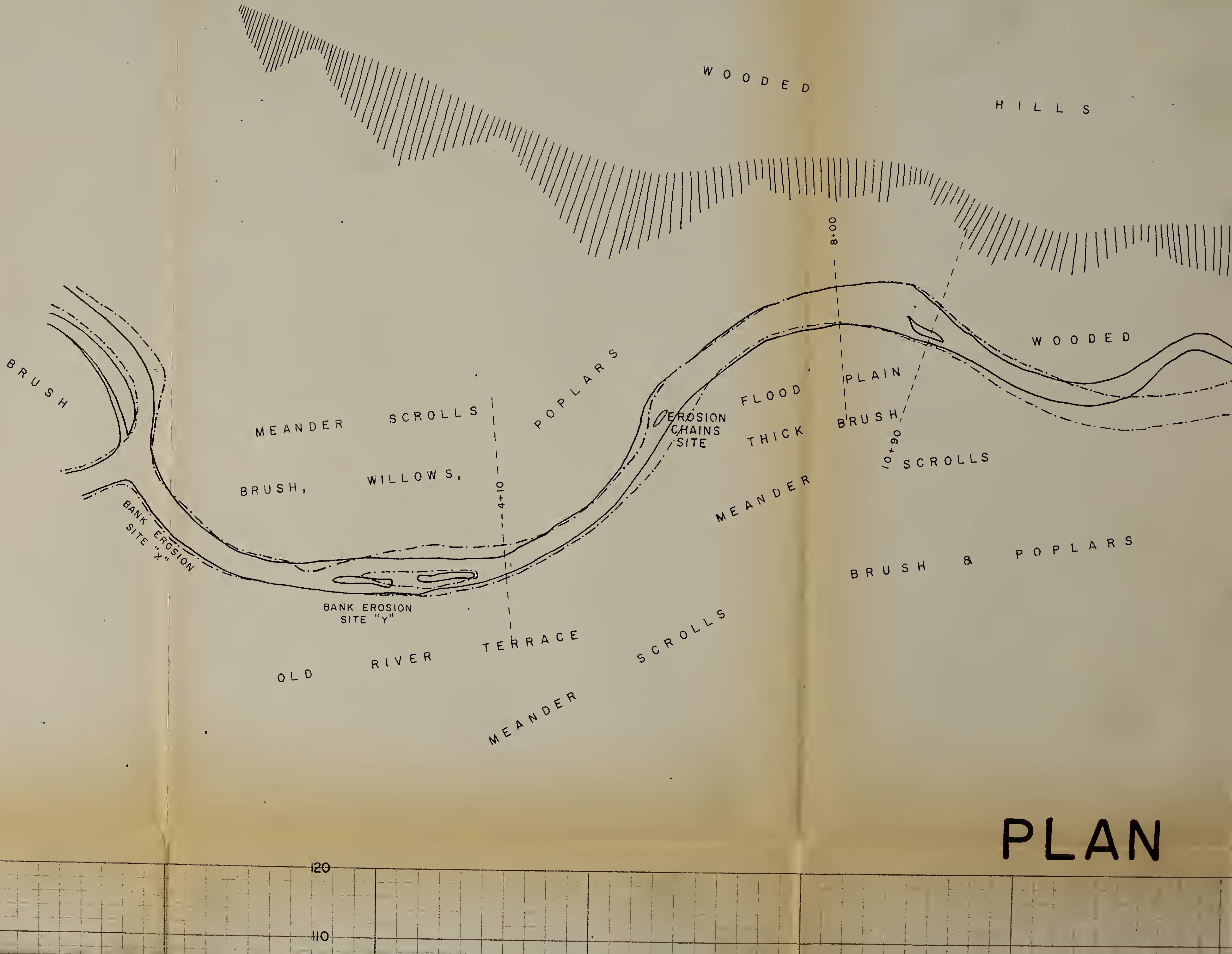
The coarse material was moving over a bed of finer material.

The data is quite crude and large scatter is expected.

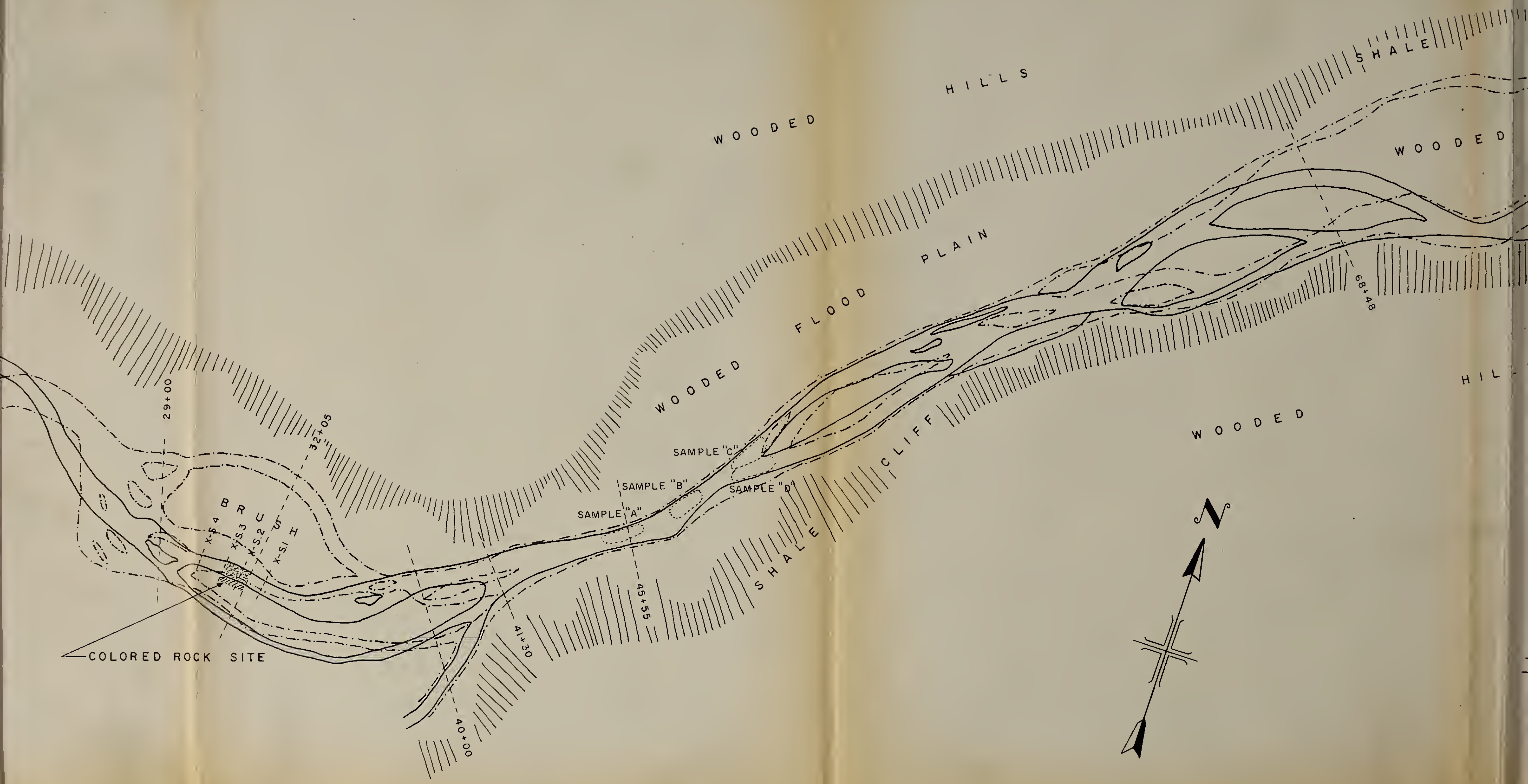
(g) Neill - Laboratory data using 8 mm. gravel: The data for this point comes from a flume study measuring the conditions at incipient motion. The experiment is just in the development stage so no further data is available. This, along with Quershi's and Bhattacharya's are the most reliable data.

The bed was composed of uniform sized material.

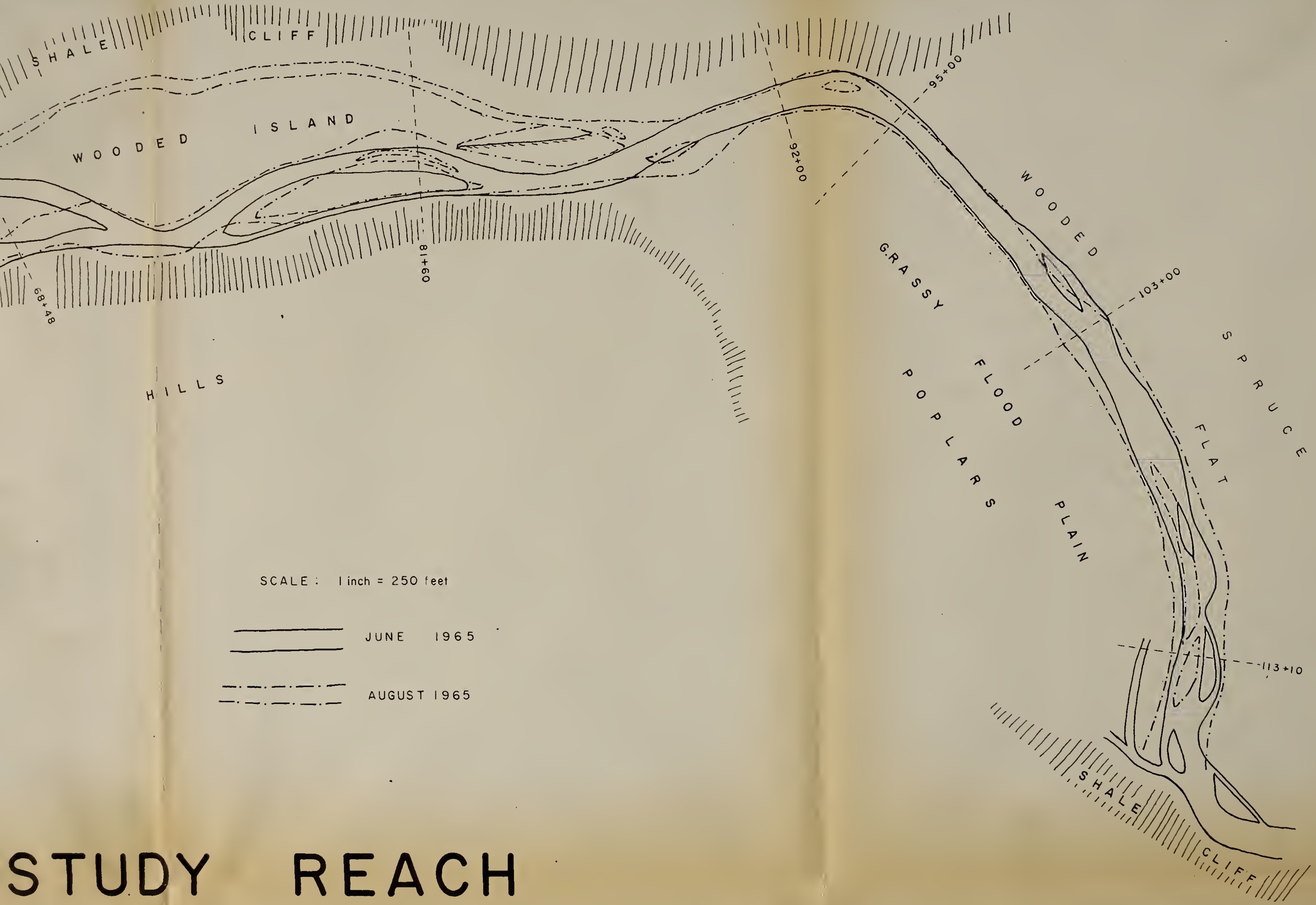
120
110


WOODED HILLS
BRUSH
MEANDER SCROLLS
POPLARS
BRUSH, WILLOWS,
4+10
8+00
10+90
EROSION CHAINS SITE
FLOOD PLAIN
THICK BRUSH
SCROLLS
WOODED
MEANDER
BRUSH & POPLARS
BANK EROSION SITE "X"
BANK EROSION SITE "Y"
OLD RIVER TERRACE
SCROLLS
MEANDER
120
110

PLAN



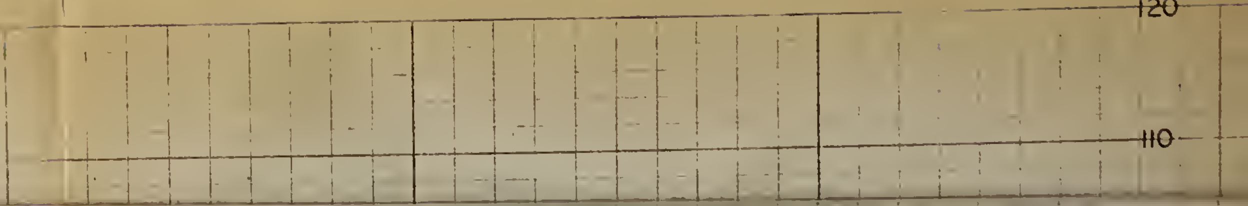
AND PROFILE OF THE ELBOW RIVER STUDY

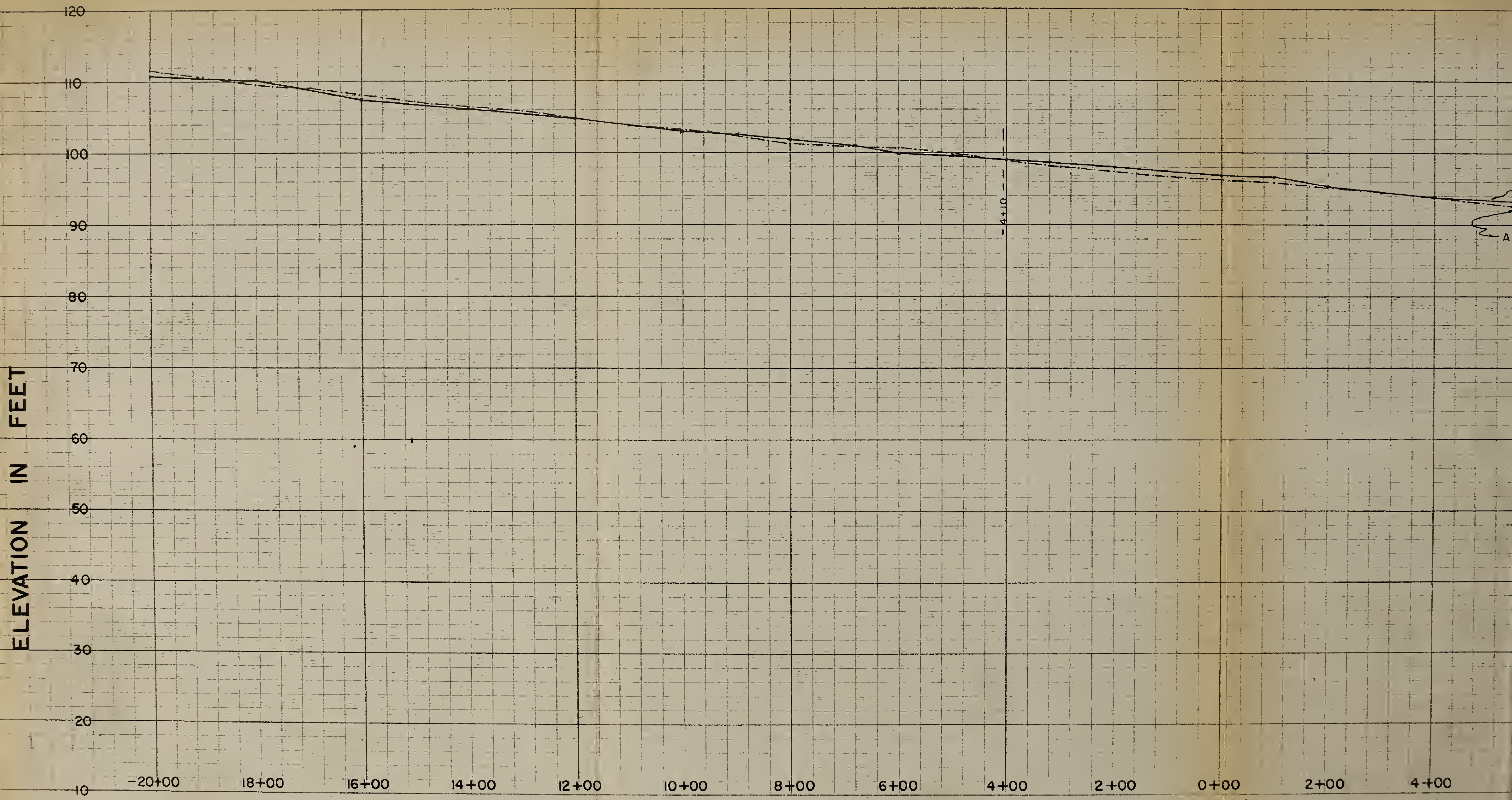

SHALE CLIFF
WOODED ISLAND
HILLS
68+48
81+60
92+00
95+00
103+00
113+10
WOODED SPRUCE FLAT
GRASSY FLOOD PLAIN
POPLARS
SHALE CLIFF
SCALE : 1 inch = 250 feet
JUNE 1965
AUGUST 1965

STUDY REACH

120
110

120
110


120
110



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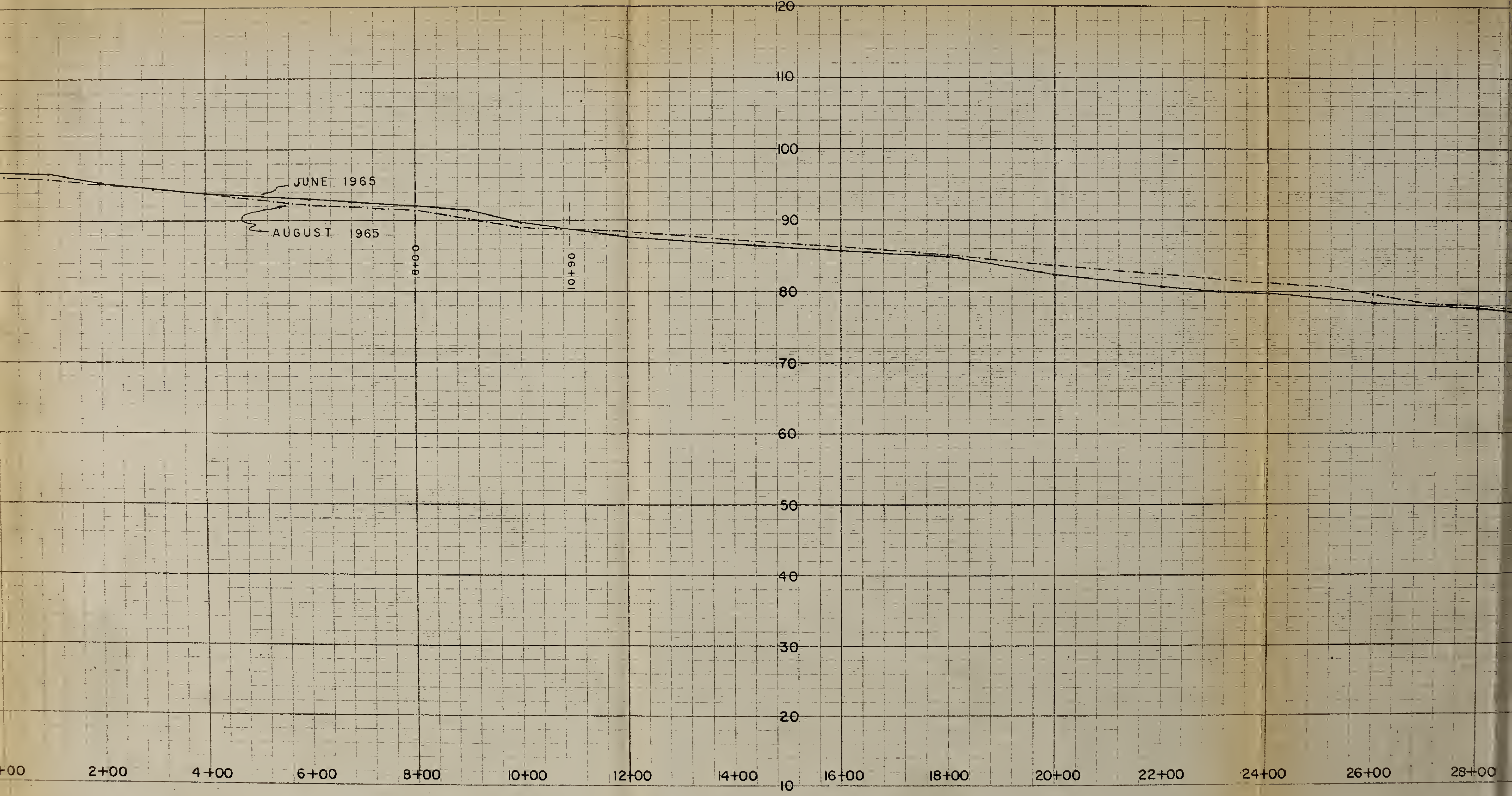

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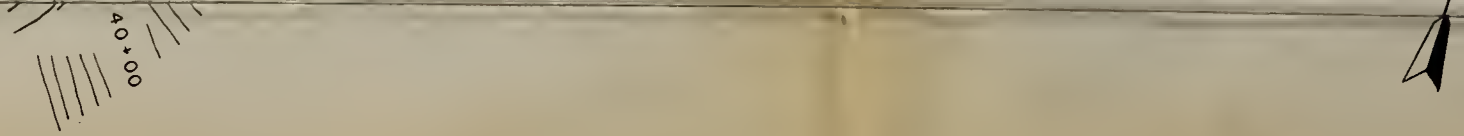
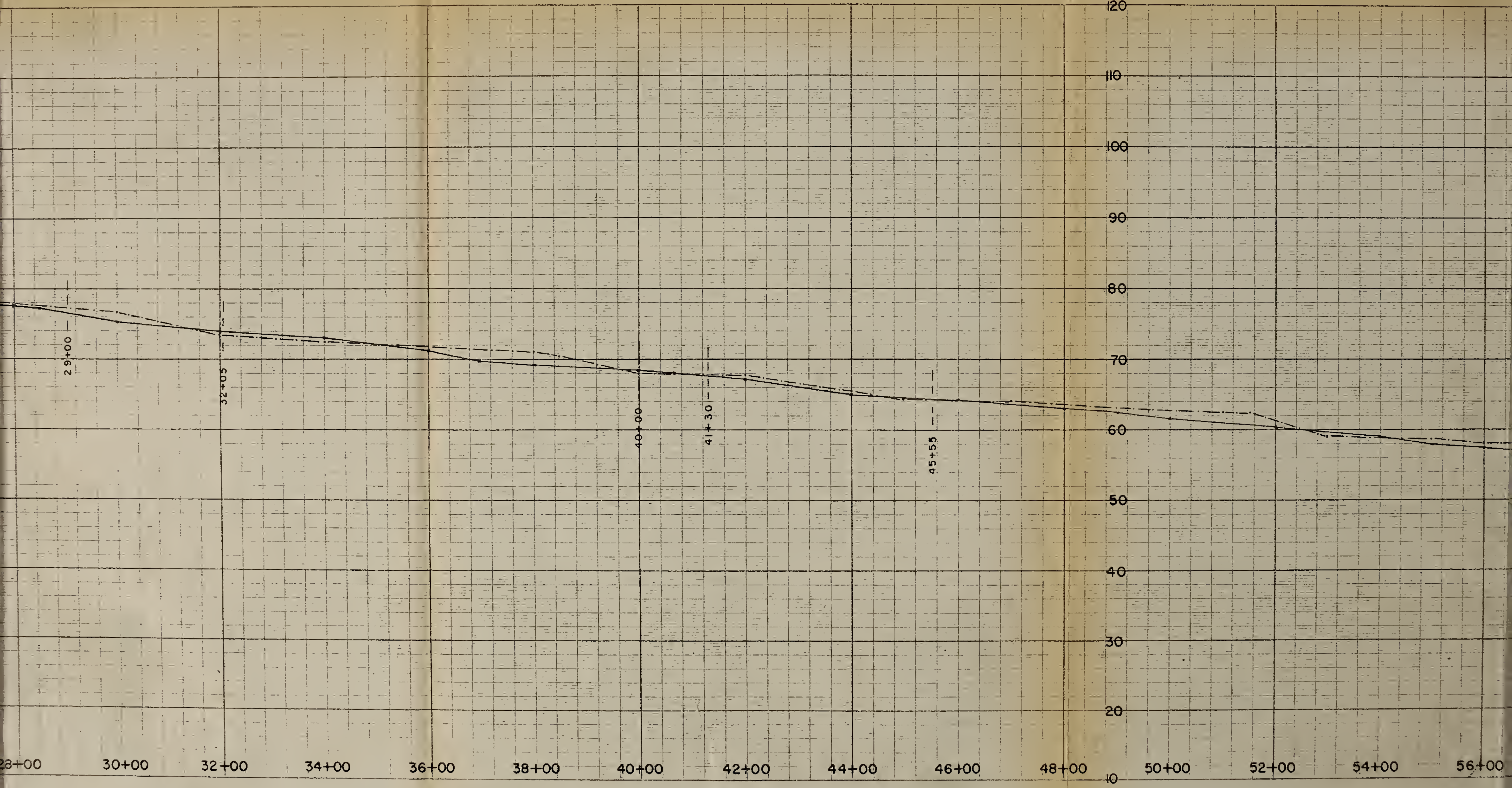


PLAN AND PROFILE OF THE ELBOW RIVER



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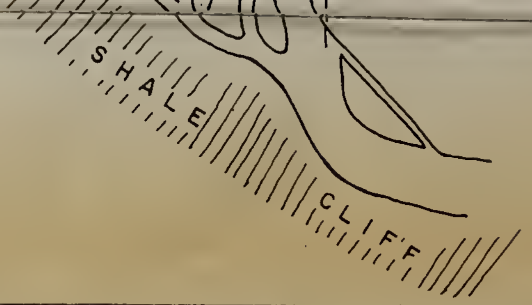
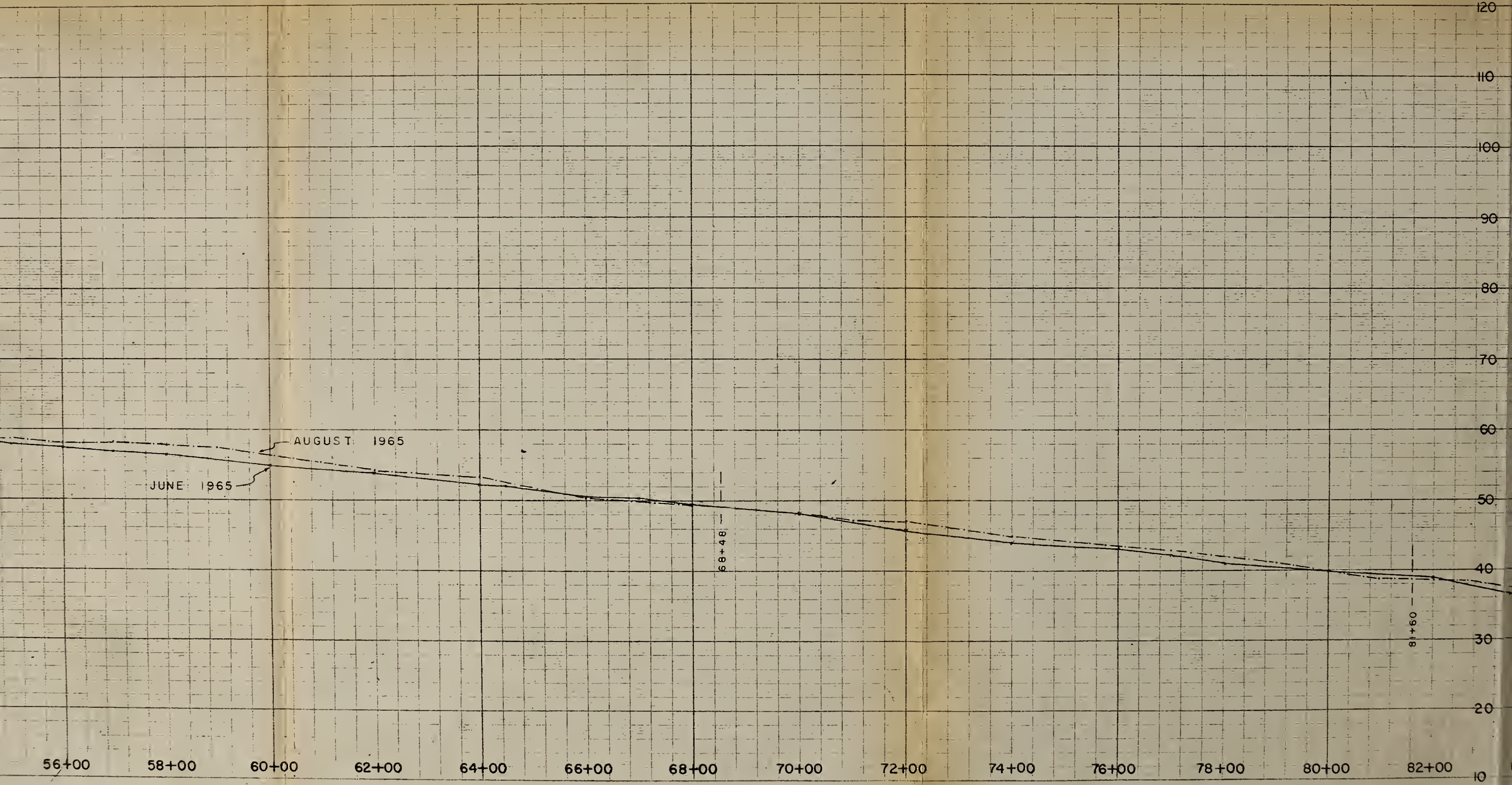


R STUDY REACH



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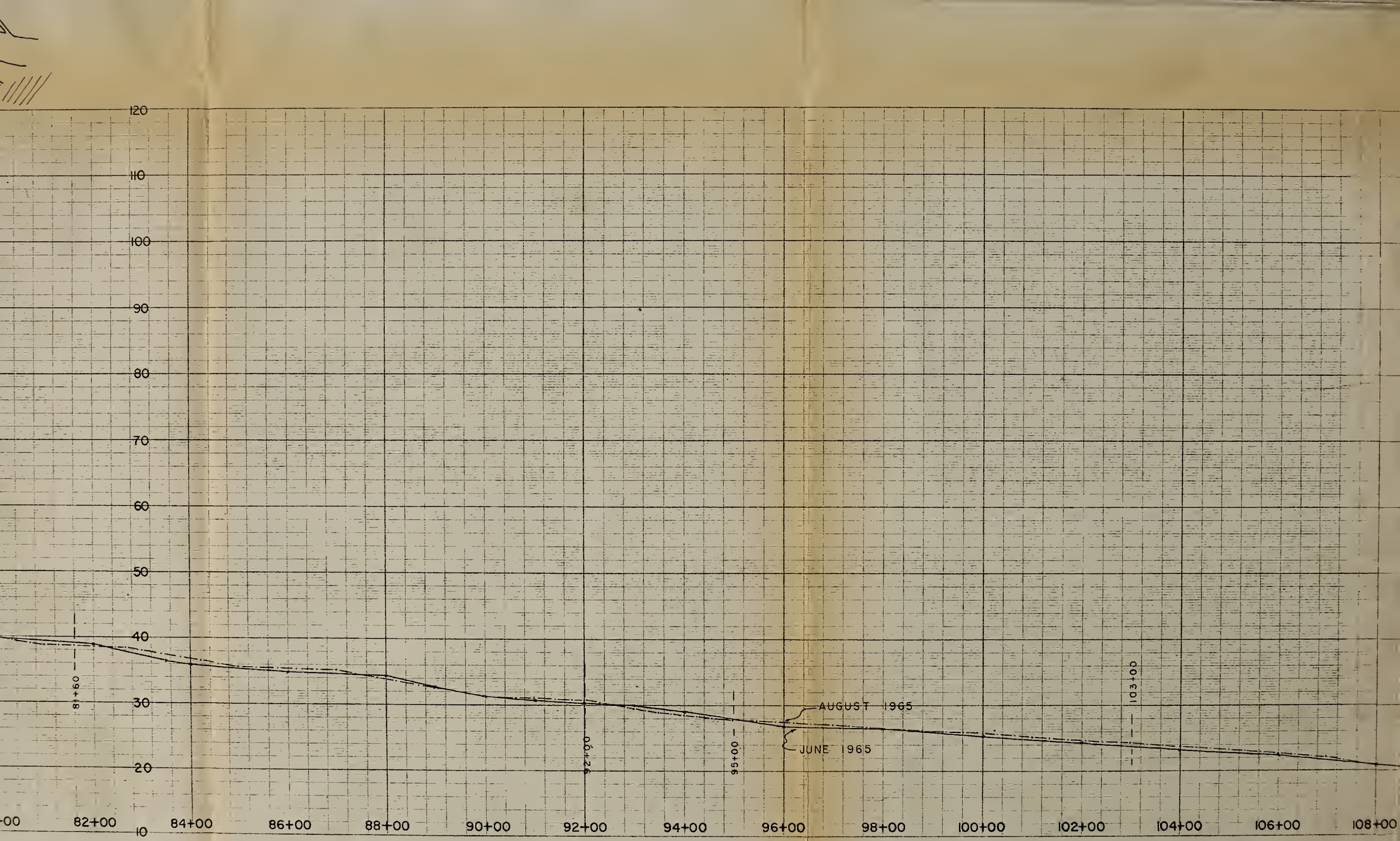

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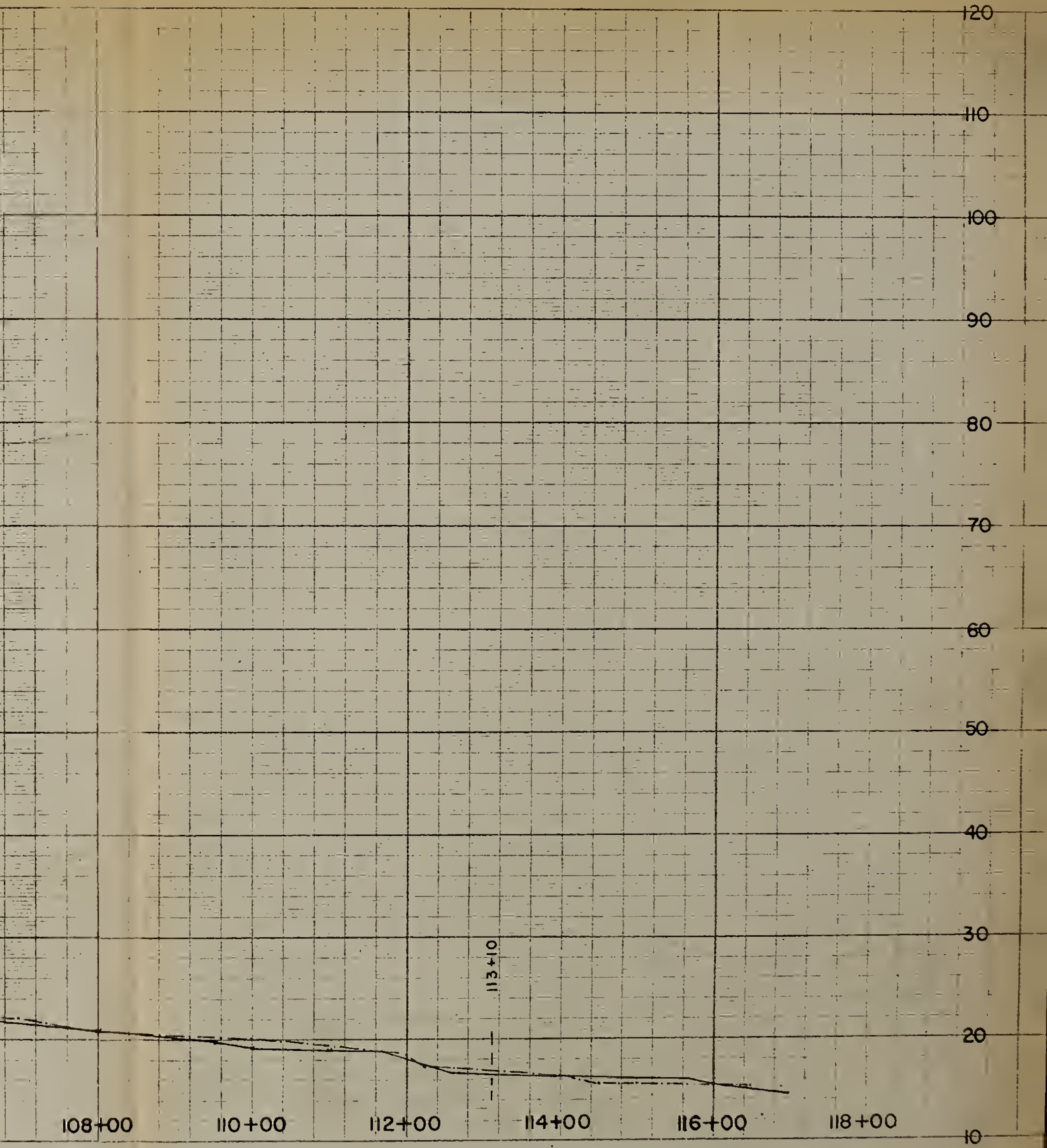

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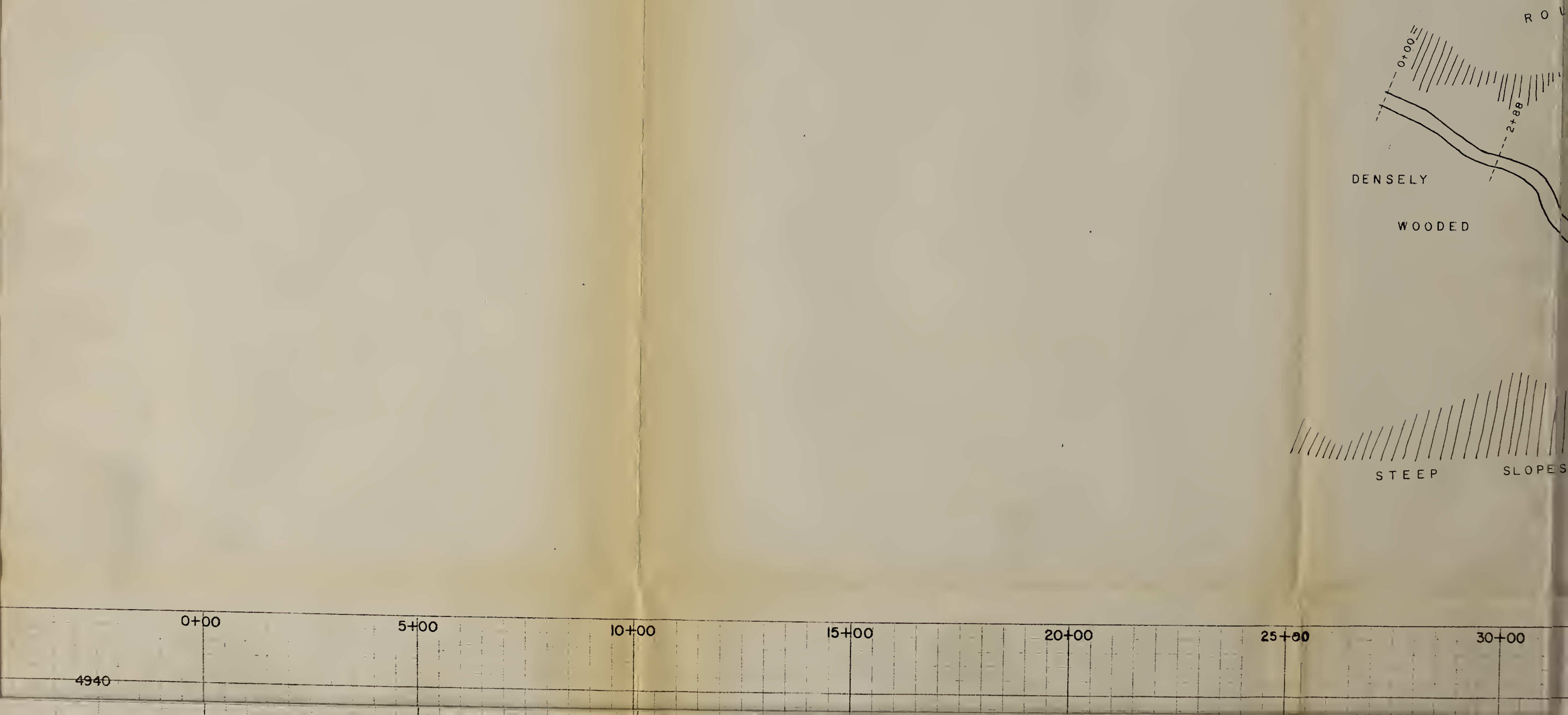
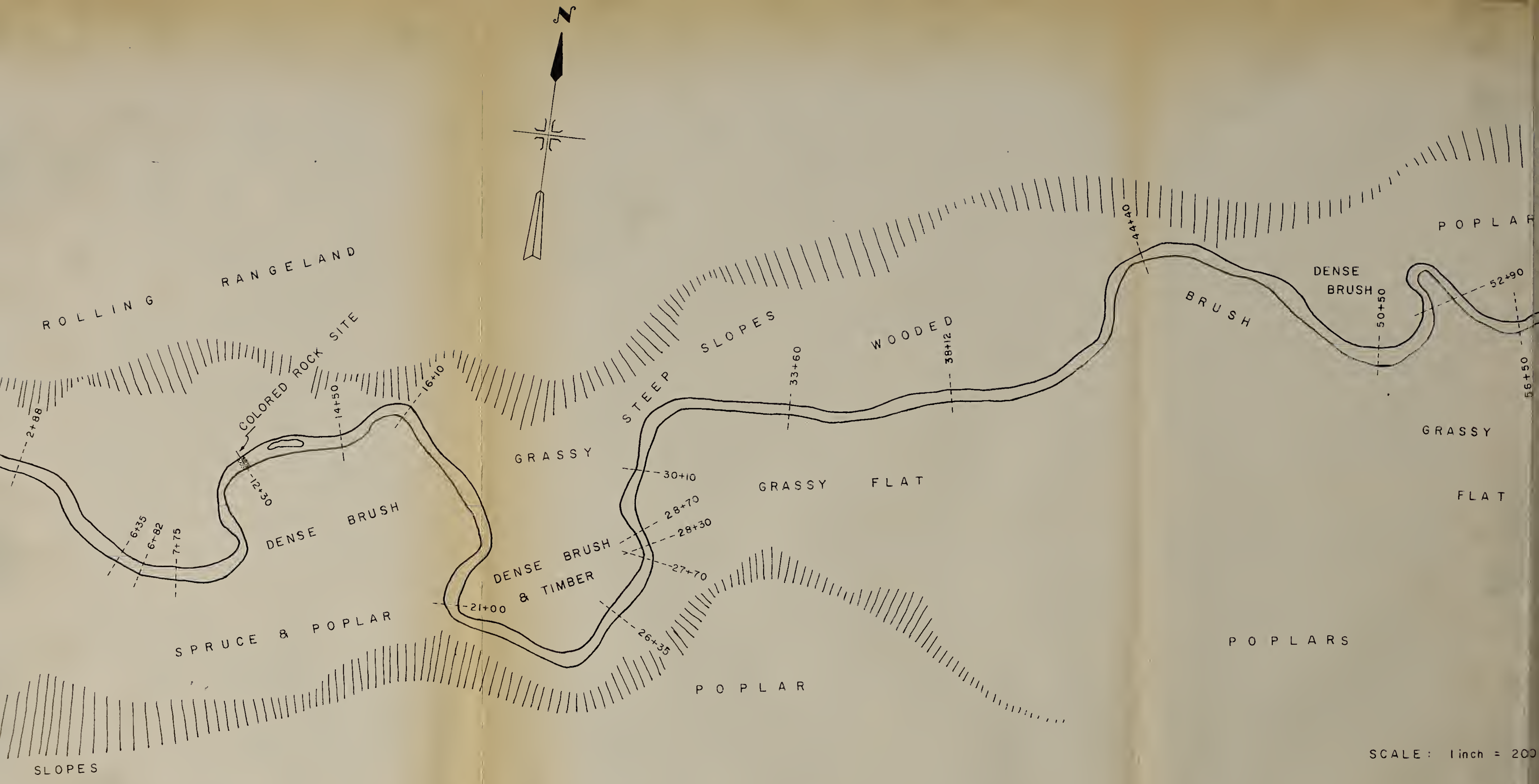

R O
0+00
2+88
DENSELY
WOODED
STEEP
SLOPES
0+00
5+00
10+00
15+00
20+00
25+00
30+00
4940



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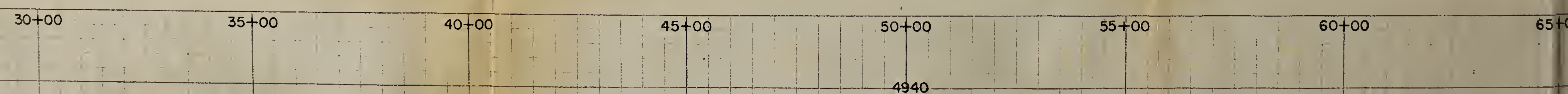
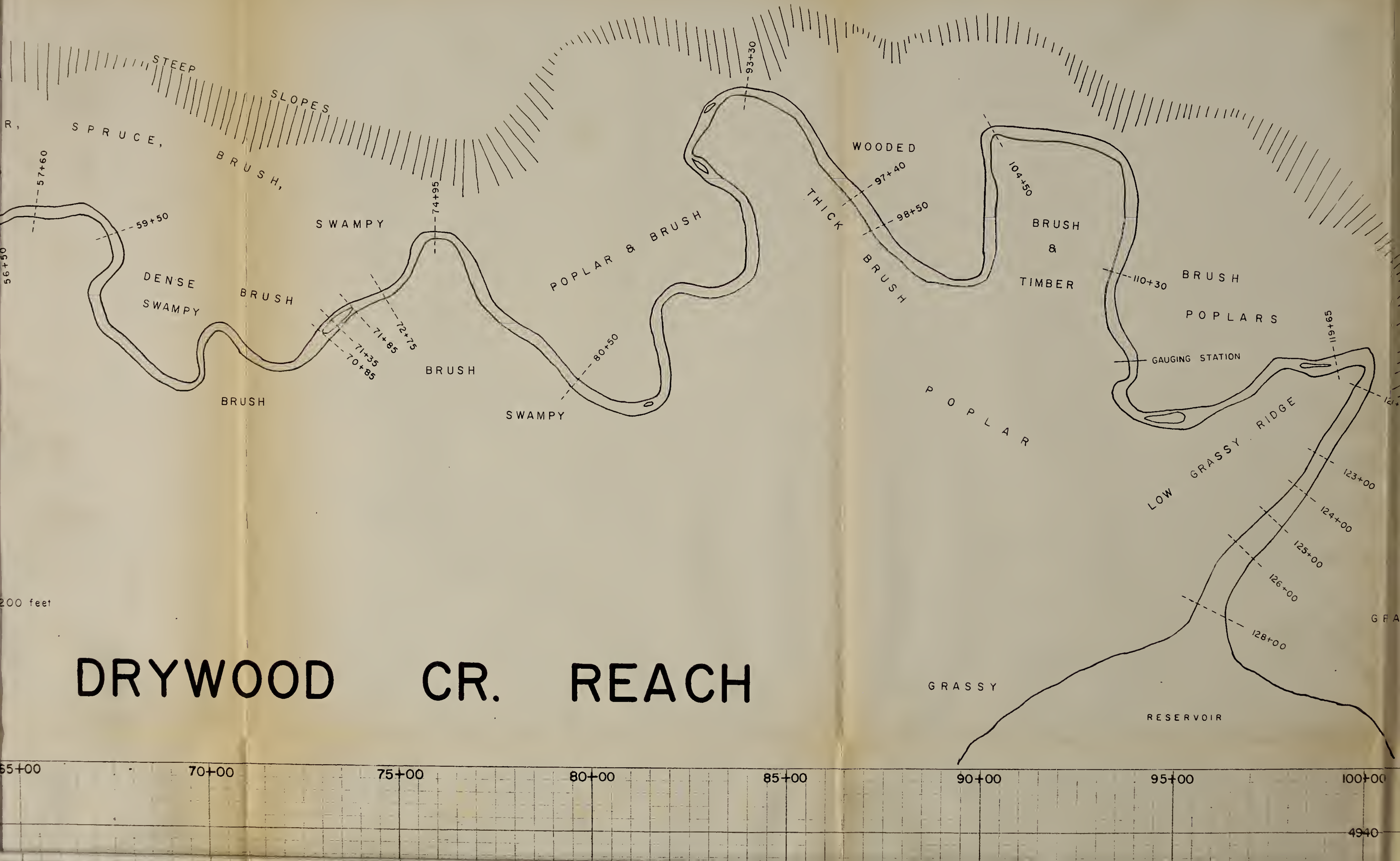
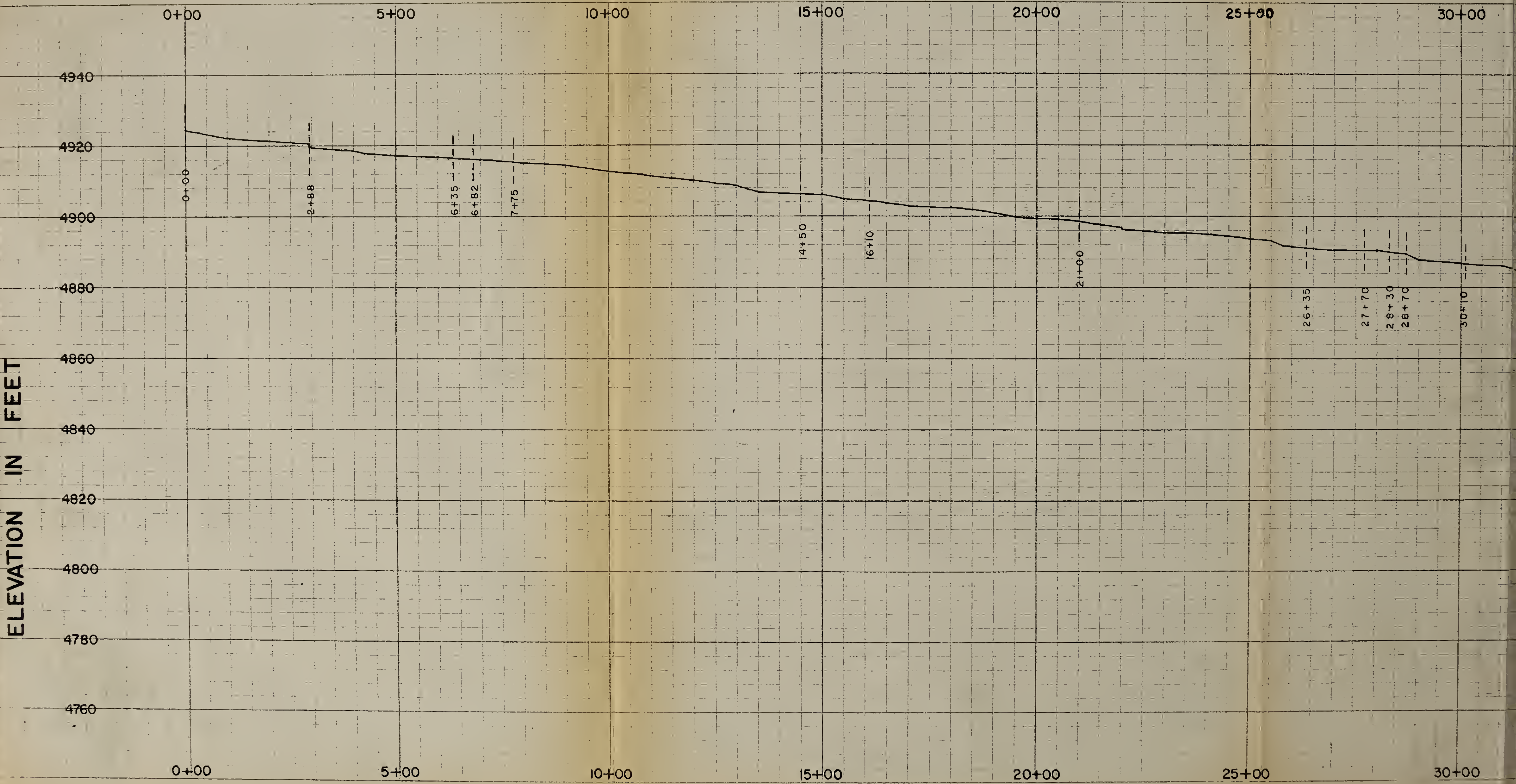




DRYWOOD CR. REACH

119+65
121+00
123+00
124+00
125+00
E
GRASSY
100+00
105+00
110+00
115+00
120+00
125+00
130+00
4940
4940



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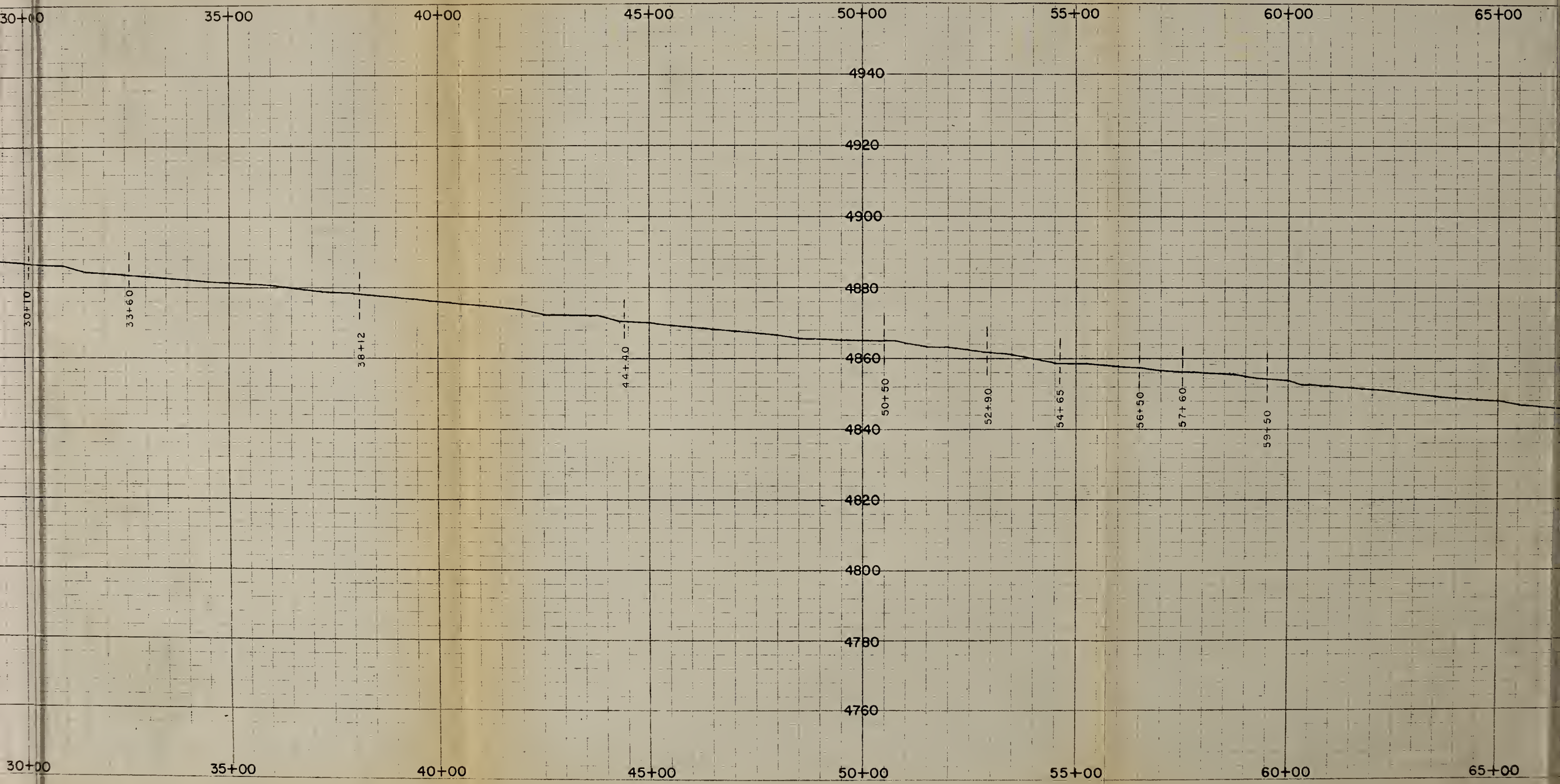

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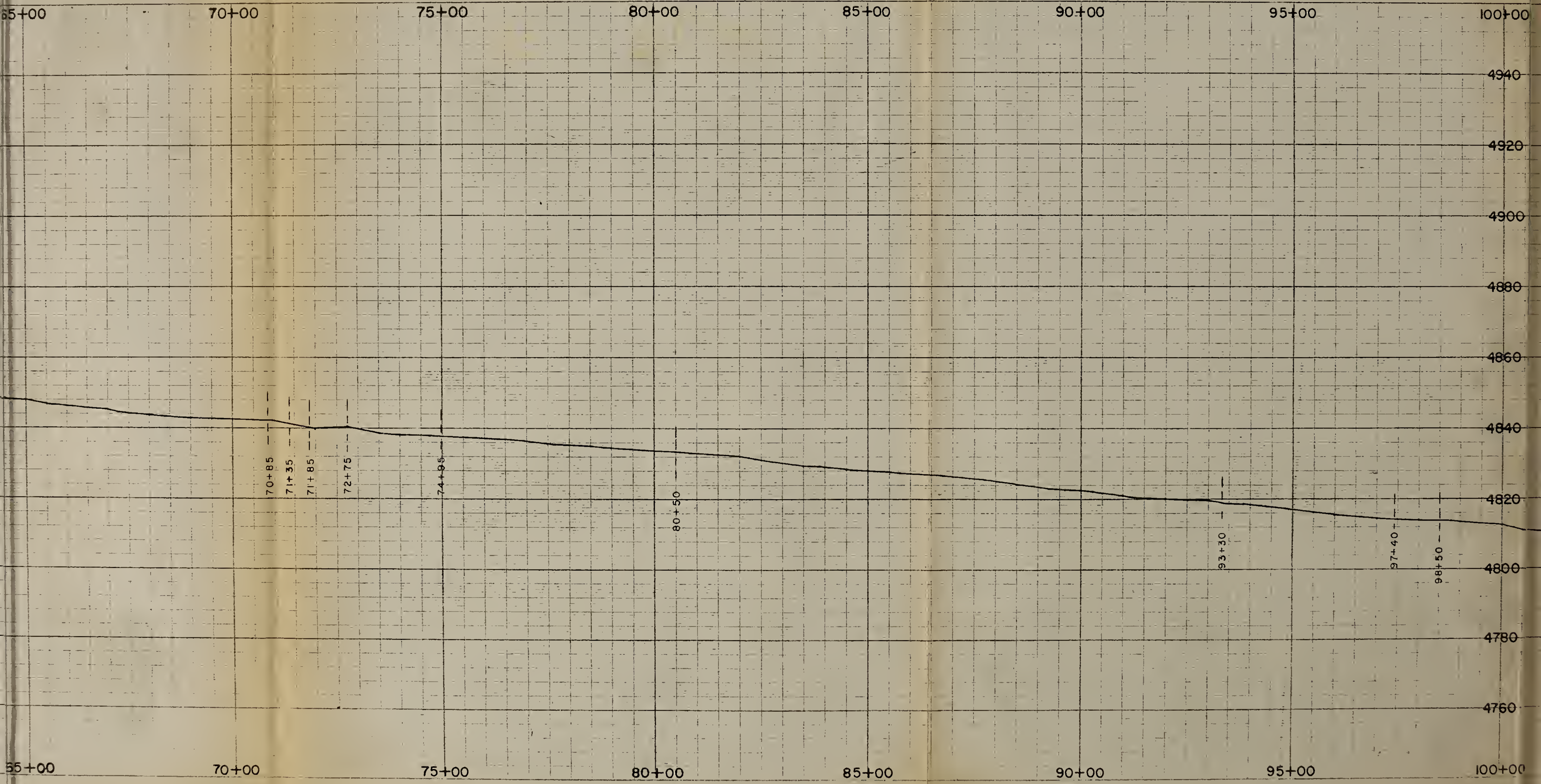

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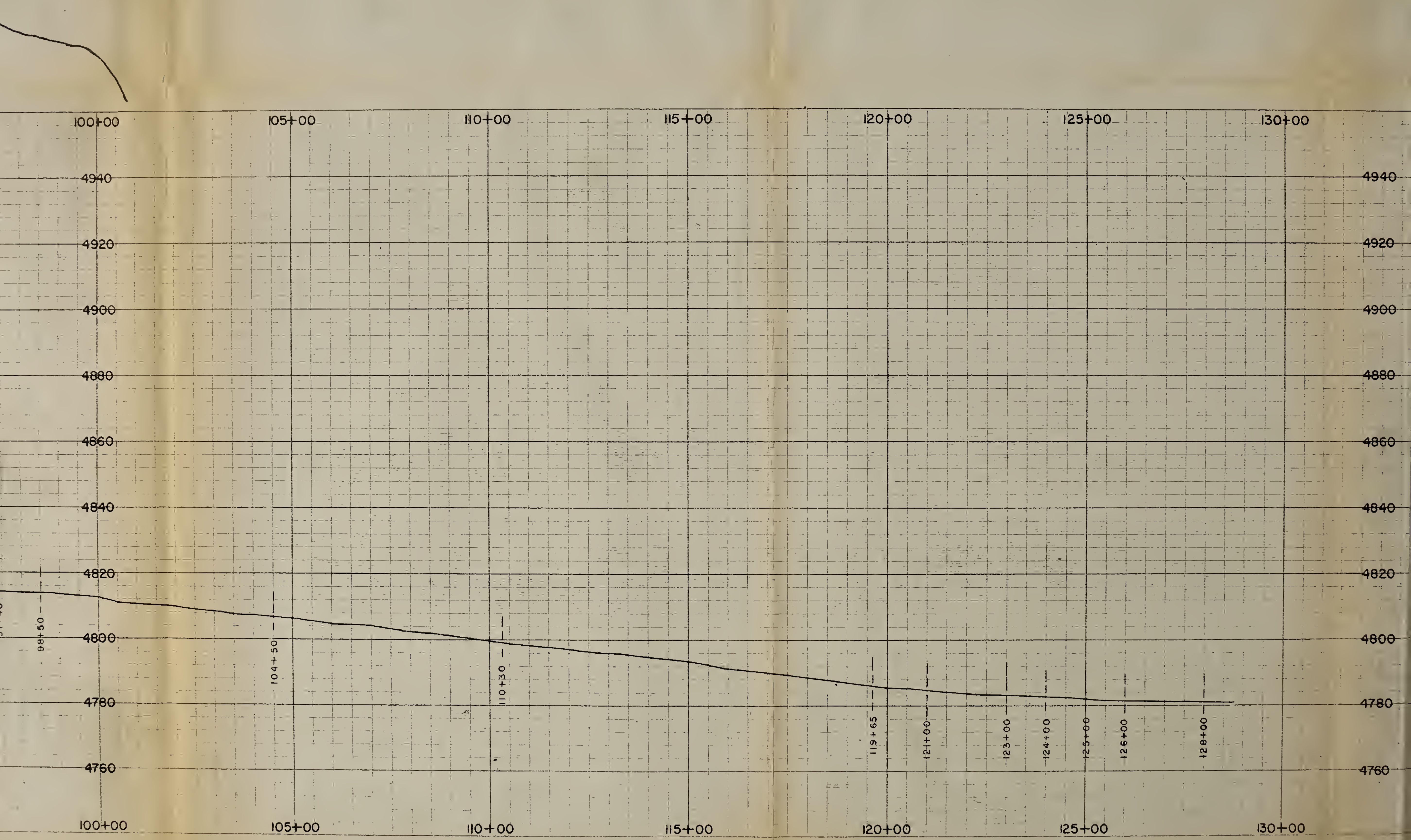

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